DTIC FILE COPY

(2)

US Army Corps of Engineers
Construction Engineering Research Laboratory

USA-CERL TECHNICAL REPORT P-89/09
December 1988

AD-A205 052

Data Envelopment Analysis as a Tool To Evaluate Efficiency of Army Real Property Management Activities (RPMA) Spending

by
Gonzalo Perez
Osman Coskunoglu
Alan W. Moore

The U.S. Army is developing an Output Oriented Resource Management System (OORMS) to compare the value of resources expended with those received for all Army programs. One of the programs to be encompassed by OORMS is Real Property Management Activities (RPMA).

The RPMA program consists of a wide range of goals from which it is difficult to identify a single, quantifiable "entity" that represents the overall goal. Thus, to enable a realistic assessment in OORMS, a performance index is needed to evaluate the efficiency of RPMA at U.S. Army installations.

Three alternative modeling techniques were considered for potential use in developing such an index. Data Envelopment Analysis (DEA) was selected because of its ability to accommodate multiple inputs and outputs simultaneously without requiring that weight and functional relationships be specified.

The performance index was applied to RPMA and its use in several stages of the resource management process was analyzed. Results were distributed to managers at the Major Command (MACOM) headquarters and installation levels for review. In general, DEA appears to be a feasible modeling technique for RPMA performance; however, the method needs refinement to enable better discrimination among efficient installations and to optimize features of the index. A prototype should be developed and implemented at the installations to test different input and output measures.

Approved for public release; distribution is unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USA-CERL TR P-89/09	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Construction Engr Research Laboratory 6b. OFFICE SYMBOL (If applicable) CECER-FS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 4005 Champaign, IL 61820-1305	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION OCE 8b. OFFICE SYMBOL (If applicable) DAEN-ZCP-B	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER OMA
8c. ADDRESS (City, State, and ZIP Code) 20 Massachusetts Ave., N.W. Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Data Envelopment Analysis as a Tool To Evaluate Efficiency of Army Real Property Management Activities (RPMA) Spending (U)

12. PERSONAL AUTHOR(S)
Perez, Gonzalo; Coskunoglu, O.; Moore, Alan W.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
final	FROM ______ TO ______	1988, December	58

16. SUPPLEMENTARY NOTATION
Copies are available from the National Technical Information Service
Springfield, VA 22161

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
05	03	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Output Oriented Resource Management System
Real Property Management Activities
OORMS (Continued)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The U.S. Army is developing an Output Oriented Resource Management System (OORMS) to compare the value of resources expended with those received for all Army programs. One of the programs to be encompassed by OORMS is Real Property Management Activities (RPMA).

The RPMA program consists of a wide range of goals from which it is difficult to identify a single, quantifiable "entity" that represents the overall goal. Thus, to enable a realistic assessment in OORMS, a performance index is needed to evaluate the efficiency of RPMA at U.S. Army installations.

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Dana Finney	22b. TELEPHONE (Include Area Code) (217) 352-6511 ext. 389 22c. OFFICE SYMBOL CECER-IMT

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Block 18. (Continued)

Data Envelopment Analysis
resource management
decision making

Block 19. (Continued)

Three alternative modeling techniques were considered for potential use in developing such an index. Data Envelopment Analysis (DEA) was selected because of its ability to accommodate multiple inputs and outputs simultaneously without requiring that weight and functional relationships be specified.

The performance index was applied to RPMA and its use in several stages of the resource management process was analyzed. Results were distributed to managers at the Major Command (MACOM) headquarters and installation levels for review. In general, DEA appears to be a feasible modeling technique for RPMA performance; however, the method needs refinement to enable better discrimination among efficient installations and to optimize features of the index. A prototype should be developed and implemented at the installations to test different input and output measures.

FOREWORD

This work was performed for the Office of the Chief of Engineers (OCE), as an Operations and Maintenance, Army (OMA) reimbursable project. The OCE Technical Monitor was Richard Nelson, DAEN-ZCP-B.

The work was conducted by the Facility Systems Division (FS) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. Osman Coskunoglu is an Associate Professor in the College of Engineering, University of Illinois at Urbana-Champaign. Dr. Michael J. O'Connor is Chief, USA-CERL-FS. The technical editor was Dana Finney, USA-CERL Information Management Office.

COL Carl O. Magnell is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

FIGURES

TABLES

DATA ENVELOPMENT ANALYSIS AS A TOOL TO EVALUATE EFFICIENCY OF ARMY REAL PROPERTY MANAGEMENT ACTIVITIES (RPMA) SPENDING

1 INTRODUCTION

Background

The U.S. Army is developing an Output Oriented Resource Management System (OORMS) to compare the value of resources expended with services received for all Army programs. According to the Army Comptroller, OORMS is intended to meet a functional requirement of Army resource management: feedback on execution in terms of outputs achieved for inputs planned, programmed, budgeted, and then used. Without this essential feedback, it is difficult to make consistent, informed assessments as to how well the Army programs are being both planned and executed. The current resource management process is missing this vital link. Decisions about Army programs and alternatives can be improved measurably if feedback is made an integral part of the process.[1]

Included in the OORMS assessments will be Real Property Management Activities (RPMA) at Army installations. The goal of RPMA is to develop, operate, and maintain the facilities necessary for the Army to accomplish its mission and provide a quality working and living environment for its personnel.[2] With such a broad, multi-objective goal, it is difficult to identify a single, quantifiable "entity" capable of representing the overall goal. In other words, to be able to quantify the degree of goal achieved by an installation, it is necessary to measure several different outputs--each accounting for a different objective--and to aggregate them properly so as to represent the amount of goal achieved. In addition, the aggregate measure of outputs has to be comparable to the amount of resources (input) deployed so that a single composite index can represent the efficiency of an installation. At present, no such index has been developed for RPMA.

Objective

The objective of this research was to develop an output-oriented performance measure index to evaluate the efficiency of RPMA at U.S. Army installations. This performance measure index should relate the outputs achieved by RPMA to the resource (input) deployed during operations; that is, it should be able to compare several types of output with several inputs simultaneously. In addition, the results of evaluations using this single index should assist in the decision-making process of resource management.

Approach

Three alternative methodologies were considered for index development: (1) data envelopment analysis (DEA), (2) ratio analysis, and (3) regression analysis. Mathematical

---

[1] *Output Oriented Resource Management System, Handbook* (Office of the Comptroller of the Army, June 1986).

[2] *Real Property Management Activities (RPMA), Executive Summary*, Vol 1 (Department of the Army Study Group, March 1978).

features of all three methods were compared and the method found most appropriate for dealing with RPMA was selected.

Input and output measures of RPMA operations were defined and selected to model performance. The performance model was applied to 21 U.S. Army Forces Command (FORSCOM) installations and the results were presented to the prospective users for evaluation. Feedback from the field was analyzed and used to revise the performance model.

2 DEVELOPMENT OF AN EFFICIENCY INDEX

Alternative Methodologies

Three different methodologies for establishing a performance index were evaluated for potential application to RPMA. Each method has already been used in some organizations to evaluate different programs.

Data Envelopment Analysis (DEA)

DEA was introduced by Charnes, et al.,[3] for measuring the efficiency of not-for-profit entities. The method has been used to measure the efficiency of several organizations such as school systems,[4] health care organizations,[5] Navy District recruiting offices,[6] fighter wings of the U.S. Air Force,[7] and RPMA in the air training commands.[8]

DEA is designed to measure relative efficiency among similar organizations, called Decision-Making Units (DMU), that share the same technology to gain similar achievements (outputs) by using similar resources (inputs). In this study, the DMUs are Army

---

[3]A. Charnes, W. W. Cooper, and E. Rhodes, "Measuring the Efficiency of Decision-Making Units," *European Journal of Operational Research*, Vol 2, No. 6 (November 1978), pp 429-444; A. Charnes, W. W. Cooper, and E. Rhodes, "Short Communication: Measuring the Efficiency of Decision-Making Units," *European Journal of Operational Research* (1979), p 331.

[4]A. Bessent and W. Bessent, "Determining the Comparative Efficiency of Schools Through Data Envelopment Analysis," *Educational Administrative Quarterly*, Vol 16, No. 2 (1980), pp 57-75; A. Charnes, W. W. Cooper, and E. Rhodes, "Evaluating Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through," *Management Science*, Vol 27, No. 6 (1981), pp 668-697; A. Bessent, W. Bessent, A. Charnes, W. W. Cooper, and N. Thorogood, "Evaluation of Educational Program Proposals by Means of DEA," *Educational Administration Quarterly*, Vol 19, No. 2 (Spring 1983), pp 82-107.

[5]H. D. Sherman, *Measurement of Hospital Efficiency Using Data Envelopment Analysis*, unpublished DBA thesis (Graduate School of Business, Harvard University, 1981).

[6]A. Lewis and R. C. Morey, "Measuring the Relative Efficiency and Output Potential of Public Sector Organizations: An Application of Data Envelopment Analysis," *International Journal of Policy Analysis and Information Systems*, Vol 5, No. 4 (December 1981).

[7]A. Bessent, W. Bessent, C. T. Clark, and J. Elam, "Constrained Facet Analysis, A New Method for Evaluating Local Frontiers of Efficiency and Performance," *Air Force Journal of Logistics* (Summer 1984), pp 2-8; C. T. Clark, *Data Envelopment Analysis and Extensions for Decision Support and Management Planning*, Ph.D. dissertation (The University of Texas at Austin, May 1983).

[8]W. F. Bowlin, *A Data Envelopment Analysis Approach to Performance Evaluation in Not-for-Profit Entities With an Illustrative Application to the U.S. Air Force*, Ph.D. dissertation (The University of Texas at Austin, December 1984); W. F. Bowlin, *Report on Evaluating the Efficiency of Real Property Maintenance Activities in the Air Training Command* (Air Force Institute of Technology, Wright-Patterson AFB, OH, November 1984).

installations or, more specifically, the RPMA organization at the installation level. The notation used to formulate DEA is:

Let DMU_j; j = 1,..,n be the set of DMUs to be evaluated.

Let I_i; i = 1,...,m be the set of input measures to be used in the evaluation.

Let O_r; r = 1,...,s be the set of output measures to be used in the evaluation.

Let $\bar{O}_j$ represent the observed output vector for DMU_j, where:

$\bar{O}_j = (O_{1j},.,O_{ij},..,O_{sj})$; O_{ij} = the amount of output $_i$used by DMU $_j$

Let $\bar{I}_j$ represent the observed input vector for DMU_j, where:

$\bar{I}_j = (I_{1j},.I_{rj},..,I_{mj})$; I_{rj} = the amount of input r used by DMU_j

Using these definitions, DEA measures the efficiency of a DMU by evaluating the ratio of weighted outputs to weighted inputs as follows:

$$\text{Efficiency of } DMU_{jo},\ h_{jo} = \frac{\sum_{r=1}^{s} U_r\ O_{rjo}}{\sum_{i=1}^{m} V_i I_{ijo}} \qquad \text{[Eq 1]}$$

where I_{ijo} = the amount of input i used by DMU_{jo} and O_{rjo} = the amount of output r used by DMU_{jo}.

In the above ratio, I_{ijo} and O_{rjo} are observed values and therefore are constants. The variables U_r (one for each output measure) and V_i (one for each input measure) are called "virtual multipliers," and their values are computed relative to all DMU_j; j=1,..,jo,..,n by solving the following mathematical formulation (Eq 2):

$$\text{Maximize:} \qquad h_{jo} = \frac{\sum_{r=1}^{s} U_r\ O_{rjo}}{\sum_{i=1}^{m} V_i\ I_{ijo}}$$

$$\text{Subject to:} \quad \frac{\sum_{r=1}^{s} U_r\ O_{rj}}{\sum_{i=1}^{m} V_i\ I_{ij}} \leq 1 \qquad j = 1,..,n$$

$$U_r \geq \varepsilon > 0$$

$$V_i \geq \varepsilon > 0 \qquad \text{[Eq 2]}$$

where ε is a non-Archimedean constant that constrains U_r and V_i to positive values.

Observe that every DMU in the set $DMU_j, j=1,\ldots,n$ is represented by a constraint in the above formulation. Hence, there are s plus m variables and n constraints, with n being the number of units compared.

The above problem has to be formulated for each DMU in the set DMU_j; $j=1,\ldots,n$. For each formulation, the set of constraints is the same, whereas the objective function represents the DMU being evaluated.

Since the DMU being evaluated, DMU_{jo}, is also represented in the constraints with less than or equal to one right-hand side, the value of the objective function is $h_{jo} = h_{jo}^* \leq 1$ with $h_{jo}^* = 1$ if DMU_{jo} is efficient relative to the other DMUs present in the constraints of Equation 3.

Note that in the above formulation (Eq 2), the optimal Us and Vs are associated with the DMU being evaluated; hence, the optimal Us and Vs vary for each DMU. Furthermore, they represent the virtual multipliers that provide the highest possible rating for the DMU being evaluated while ensuring that such multipliers are also feasible for the other n-1 DMUs. In other words, the formulation ensures that the efficiency rating assigned to a DMU is the best one possible, and that no other set of weights (Us and Vs) will assign a higher efficiency rate.

Therefore, when the efficiency of DMU_{jo} is less than 1, it follows that the jo^{th} unit is strictly inefficient compared with some other DMUs in the set. The subset of DMUs against which the jo^{th} unit is compared is called the "jo^{th} unit reference set"; this subset consists of DMUs for which the constraint is equal to 1 at optimality. In addition, DEA results provide ways to project the inefficient unit into its reference set so that it becomes efficient.

The formulation given in Equation 2 is an extended nonlinear programming formulation of an ordinary fractional programming problem. However, Charnes, et al.[9] have shown that it can be transformed into an equivalent linear programming problem using the linear fractional programming theory developed by Charnes and Cooper.[10] Appendix A explains the linear programming formulation and its solution.

Ratio Analysis

This approach has been used widely to measure performance in almost every type of organization. The performance measure is determined by evaluating the ratio between a weighted sum of inputs and a weighted sum of outputs. To do this, the weights are predetermined--not calculated as in DEA. This method is well suited for rating among units in which inputs and outputs can be quantified using the same measuring unit (e.g., U.S. dollars).

---

[9]A. Charnes, W. W. Cooper, and E. Rhodes (1978); A. Charnes, W. W. Cooper, and E. Rhodes (1979).

[10]A. Charnes and W. W. Cooper, "Programming With Linear Fractional Functionals," *Naval Research Logistics Quarterly*, Vol 9 (1962).

When inputs and outputs do not share the same measuring units, it can become difficult to find a meaningful performance ratio. Furthermore, the complexity of the problem increases when the relationships between input and output are unknown.

Several relatively simple ratios might be used to model single relationships between different sets of inputs and outputs. However, the separate ratios do not explicitly recognize the joint use of these inputs to produce a combination of outputs. Therefore, a unit may be rated highly efficient based on one of these ratios, while the same unit may be rated inefficient with respect to a different ratio. This situation leads to some ambiguity as to whether a unit is efficient or inefficient, and calls for a method of establishing different priorities (weights) among the separate ratios to generate an overall efficiency ratio.

However, when dealing with a few relevant outputs and the priorities among them are clear, ratio analysis allows management to stress the goals of the organization more effectively than with DEA. Furthermore, ratio analysis provides a way to penalize deviation in the inputs or in the outputs from some preestablished targets. Also, it permits management to change the priorities of the goal from time to time when the needs of the organization call for it.

The weaknesses of ratio analysis are that: (1) when aggregating many inputs and outputs, the index loses meaning, (2) goals that do not show in the index are disregarded by lower level management, and (3) the design of the ratio may need to be rather complex to avoid ambiguity.

Regression Analysis

This approach, although not as widely used as ratio analysis, is very popular among many organizations for estimating relationships between one input and one output (linear regression). Regression analysis usually performs well when used to evaluate systems of one input and a few outputs or vice versa--one output and several inputs. The approach can be viewed as a technique to design a *ratio*, in which case regression analysis simplifies the modeling of unknown relationships among inputs and outputs. On the other hand, regression analysis does not allow managers to emphasize selected goals and targets over the others.

Methodology Selection

Upon analyzing features of the three methods, it became clear that DEA offered several advantages over the other two methods for evaluating the efficiency of RPMA. These advantages are summarized here; for a more extensive comparison, refer to Bowlin, et al.[11] and Banker, et al.[12]

[11] W. F. Bowlin, A. Charnes, W. W. Cooper, and H. D. Sherman, *A Comparative Study of Data Envelopment Analysis and Other Approaches to Efficiency Estimation*, Research Report CCS 451 (Center for Cybernetic Studies, The University of Texas at Austin, September 1983).

[12] R. D. Banker, R. F. Conrad, and R. P. Strauss, "A Comparative Application of Data Envelopment Analysis and Translog Methods: An Illustrative Study of Hospital Production," *Management Science*, Vol 32, No. 1 (January 1986), pp 30-44.

DEA differs from ratio analysis in that it handles multiple inputs and outputs simultaneously without requiring *a priori* specification of weights. Moreover, the production function, i.e., efficient input-output relationship, need not be known to evaluate efficiency with DEA.

DEA differs from regression analysis and related statistical techniques in that it is nonparametric and thus does not require specification of the functional forms and relations to be used. In addition, DEA evaluates the efficiency of a DMU against the most efficient DMUs (i.e., the efficiency "frontier") and not against interior DMUs (average).

There are, however, two limitations to DEA that should be mentioned:

- DEA will not necessarily locate all inefficient units; in other words, DEA measures only relative inefficiency.

- DEA is capable of addressing efficiency only and does not attempt to evaluate the effectiveness of the inputs used and/or the outputs obtained.

DEA Application Process

The DEA method is implemented in three steps: (1) identification of units to be evaluated, (2) identification of input and output measures, and (3) application of DEA and analysis of results.

Step 1: Identification of Units To Be Evaluated

Managers should identify the organizational units for which a DEA efficiency evaluation would be of interest. Generally, this parameter would be a set of units that provide similar services and whose performance management wants to evaluate to improve efficiency. For this study, the units to be evaluated are the RPMA organizations at the installation level.

Step 2: Identification of Input and Output Measures

Managers should identify the relevant inputs and outputs of units to be evaluated as measured over a representative period of time (e.g., for 1 year, quarter, or month). Relevant outputs are those services and other activities for which the unit is responsible in achieving its mission (i.e., goals). Relevant inputs are the resources required to produce the designated outputs.

Field applications of DEA have indicated that this process of output and input identification often is by itself useful to managers, as outputs and inputs sometimes are not explicitly identified or understood. In addition, some of the relevant outputs and inputs may not have been measured or captured in the current information system. The absence of data on relevant outputs and inputs has raised questions about the adequacy of the information system, since this type of input/output data is needed to assess operating performance regardless of the techniques used.

Unless all relevant outputs and inputs are included in the DEA analysis, the DEA results will have to be reviewed for any bias that might result. There are four general guidelines for selecting the input and output measures:

1. The inputs and outputs should be comprehensive. That is, they should fully and properly measure the RPMAs.

2. There should be some basis for believing that the relationship between inputs and outputs is such that an increase in an input can reasonably be expected to increase one or more of the outputs.

3. All input and output measures should exist in positive amounts for each installation.

4. The variables should be identifiable and defined and controlled so that they cannot be manipulated in reports, or at least the resulting data should be reviewed to remove these effects which might otherwise influence the results of the performance model. As discussed earlier, DEA not only rates efficiency among installations, but also provides additional information regarding the efficiency of input usage and output achievement. Therefore, the choice of inputs and outputs will determine the value of information provided by the model. In other words, a choice of meaningless input and output measures will yield meaningless managerial information. Hence, to fully exploit the capabilities of DEA, two more guidelines were used for selecting input and output measures in this particular application:

5. The level of detail in defining inputs and outputs should be sufficient for Office of the Chief of Engineers (OCE)-level planning, programming, and budgeting activities.

6. Existing data sources should be used whenever possible, rather than generating new data.

Step 3: Application of DEA and Analysis of Results

At this point, the results of DEA may not be consistent with prior perceptions of the units evaluated. This outcome, in turn, may raise questions about how complete and representative the output and input measures are. In this way, the analysis may result in refinements to the set of inputs and outputs used in the model.

Identification of Input Measures

In general terms, there are two inputs: monetary funds and space used for supporting RPMA. Monetary funds, as a single input term, may not serve the purposes at the OCE level. Two alternative disaggregation schemes are possible:

1. According to the destination of the funds (labor, materials, utilities, and equipment), or

2. According to the current accounting system (J, K, L, and M accounts).

Furthermore, the level of disaggregation can be considered at different details (e.g., type of labor, or J_1, J_2). Given that the main purpose of performance measurement is planning, programming, and budgeting at the OCE level, the following input list is recommended (Figure 1):

I_1: Cost of operation of utilities: J account.

I_2: Cost of M&R of real property: K account.

I_3: Cost of minor construction: L account.

I_4: Cost of engineering support: M account.

I_5: Square feet of maintenance and production buildings.

Identification of Output Measures

In general terms, the RPMA resources are used to:

1. Accommodate and provide services to Army personnel.

2. Maintain and repair facilities.

Therefore, outputs can be divided into two major groups: those related to personnel and those related to the physical plant. This division is shown in Figure 2 and is explained below.

Personnel Related Outputs

Quantity as well as quality of the service provided to persons living and working at the installations should be considered. Therefore, the following outputs are proposed:

O_1: population served; measures the quantitative aspect of serving people.

O_2: (population served)/(number of complaints + 1); measures the quality of service provided to the people.

Note that, as the number of complaints decreases, O_2 increases. Hence, O_2 can be perceived as a surrogate measure for the quality of life at an installation.

Facility (Physical Plant)-Related Outputs

An Army installation does not have an external output. Moreover, internal outputs are difficult to measure, as with any nonprofit organization.

In a resource management system, one way of determining the outputs is to answer this question: for what purposes are the resources used at an installation? The physical facilities use the inputs (resources) listed above in two ways:

1. As space and surface that require maintenance, repair, and upgrading.

2. As space that consumes energy.

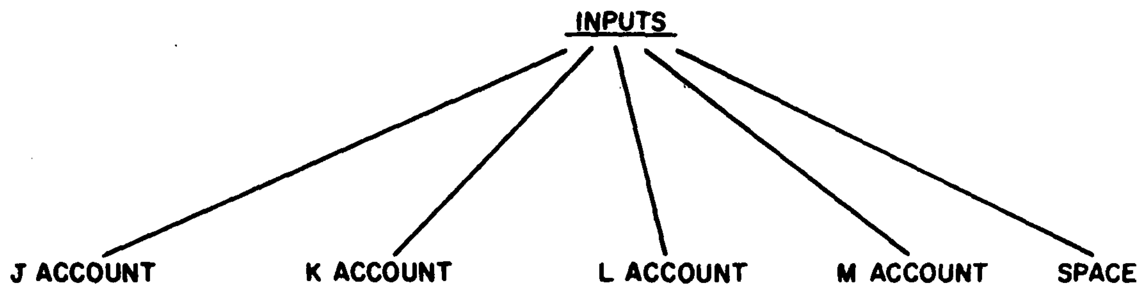

Figure 1. RPMA inputs.

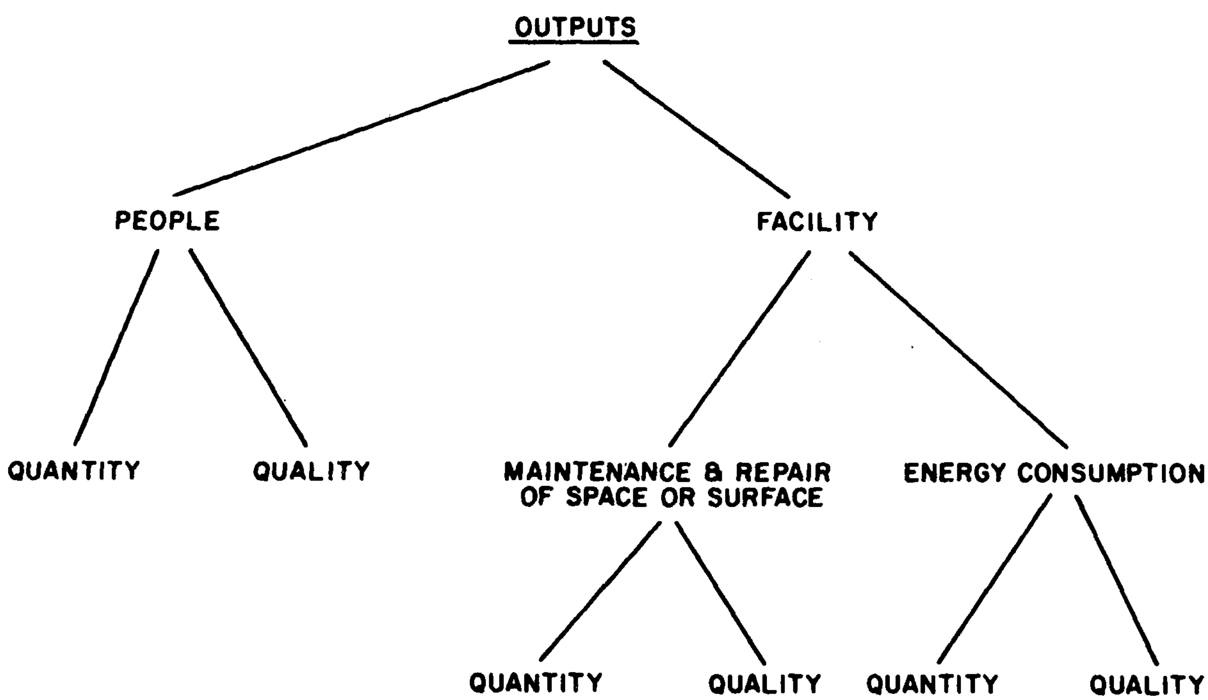

Figure 2. RPMA outputs.

The amount of space and surface maintained, repaired, and upgraded is an output; likewise, the quality of these services is an output, as is the amount of space that consumes energy. However, the quality of energy consumption is not considered here, since it is an output of a different Army program--the Energy Conservation Improvement Program--(ECIP), not of RPMA.

The relationship between the outputs and inputs proposed can vary substantially from one facility to another. The following features of the facilities introduce this variance:

- Function (e.g., warehouse versus hospital),
- Structural characteristics (e.g., paved surface versus building),
- Geographic location.

Therefore, the specific definitions of the outputs should account for these features. In view of these considerations, the following outputs are proposed:

O_3: Cost of duplicating the existing facility. This duplication cost (DC) can be computed as follows:[13]

DC = Acquisition Cost x Index (1) + Historical Renewal Costs x Index (2).

Renewal includes improvements in the existing facility, but excludes maintenance and repair. Indexes 1 and 2 can be obtained from the Building Construction Index published by the *Engineering News Record.*

O_4: Total of backlog maintenance and repair (BMAR) and deferred maintenance and repair (DMAR). This output is undesirable; therefore, the inverse, 1/(BMAR + DMAR), should be used in the performance formula.

O_5: Number of square feet of building space conditioned; modified by a building type energy use factor[14] and by heating/cooling degree days.

The output O_3 represents the "quantity" of the physical facilities maintained and repaired; it accounts for the functional, structural, and locational differences between the facilities. Furthermore, O_3 is directly related to the inputs proposed under **Identification of Input Measures.** Therefore, it is a more useful measure than square feet of the facilities maintained and repaired.

The BMAR and DMAR values in output O_4 are commonly used as surrogate measures of the facilities' physical condition. They also account for the functional, structural, and locational differences among facilities. Therefore, in the absence of a more direct measure for the condition of the facilities, O_4 can be used as a surrogate measure for the quality of maintenance and repair consumption.

---

[13]O. Coskunoglu, "Appraisal of Army's Facilities," RPMA Information Paper No. 37 (U.S. Army Construction Engineering Research Laboratory, November 1985).

[14]Developed by the U.S. Army Construction Engineering Research Laboratory (USACERL); see *Design Criteria*, Architectural and Engineering Instructions (OCE, Engineering Division, 13 March 1987). Available through PAXMAIL.

Finally, O_5 is a measure of output pertaining to energy consumption. Again, it accounts for the functional, structural, and locational differences among facility types.

Data Availability

To avoid having to generate new data, a compromise was reached between desirable data and data on-hand. As a result, the list of inputs and outputs used in this study can be summarized as:

O_1: Number of people living and working at the installation.

O_2: Not used.

O_3: Redefined as millions of square feet of building area.

O_4: 10^9/BMAR; only BMAR is used.

O_5: (building area in sq ft) x (USA-CERL energy factor for building type and location).

I_1, I_2, I_3, I_4: Total J, K, L, and M accounts, respectively.

I_5: Total area of the buildings (sq ft) used for maintenance and repair purposes.

3 DEA COMPUTATIONS AND RESULTS

Computations

A portable personal computer (Compaq 286) with an off-the-shelf linear programming package (Vino) was used to solve the DEA computations. Vino was chosen because it reads data from Lotus 1-2-3, which is the most popular spreadsheet program.

Results were computed for two major commands (MACOMs) over 3 fiscal years as follows:

1. MACOM #1, FY85
2. MACOM #1, FY84
3. MACOM #1, FY83
4. MACOM #2, FY85
5. MACOMs #1 and #2, FY85; joint analysis.

The results for each computation are explained in Appendix B. Table 1 summarizes the results of MACOM #1 for FY85.

Table 1

Summary of Results for MACOM #1 in FY85

Installation	Efficiency Rate (%)	Reference Set*	No. of Times in Reference Set**
1	100.00	1	2
2	100.00	2	0
3	100.00	3	4
4	100.00	4	0
5	95.13	10,15,20,21	-
6	93.74	1,12,14,21	-
7	87.86	3,10,14,20	-
8	99.11	1,14,21	-
9	100.00	9	2
10	100.00	10	7
11	100.00	11	1
12	100.00	12	1
13	69.67	10,15,20,21	-
14	100.00	14	3
15	100.00	15	5
16	75.15	3,9,10,15,20	-
17	55.11	10,15,20	-
18	89.37	3,9,10,15,20	-
19	65.89	3,10,11	-
20	100.00	20	6
21	100.00	21	4

*The set of 100 percent efficient installations against which the inefficient installation is compared. Also see the section Alternative Methodologies and Appendix A.

**The more times an installation is in a reference set, the more indisputable its efficiency. Furthermore, when an installation is rated 100 percent and it is not in any reference set, its efficiency can be questioned.

Installations within MACOM #1 that were rated 100 percent efficient in each of the 3 years examined were numbers 3, 9, 10, 11, 12, 15, and 20. In contrast, the set of installations rated as less than 100 percent efficient in each of those same 3 years included numbers 6, 13, 16, and 18.

To further review and validate the results obtained for MACOM #1 from this analysis, data were gathered for FY85 from 21 installations in MACOM #2 and combined with those of MACOM #1 for a joint analysis. With this approach, more observations could be included in the analysis which should provide better overall efficiency in the evaluations. Even if the two sets of installations are not quite comparable, it should appear in the results as a consistent separation of their efficiency evaluations.

Tables 2 and 3 compare the efficiency rating calculated using FY85 annual data when the MACOMs were analyzed separately (column 2) and when they were analyzed together (column 3).

Table 2

Comparison of Efficiency Ratings—MACOM #1 and Joint Analysis (FY85)

Installation	MACOM #1	MACOMs #1 & #2
1	100.00	100.00
2	100.00	98.38
3	100.00	98.69
4	100.00	100.00
5	95.13	95.13
6	93.75	88.35
7	87.75	83.33
8	99.12	93.57
9	100.00	100.00
10	100.00	100.00
11	100.00	93.44
12	100.00	100.00
13	69.67	69.67
14	100.00	100.00
15	100.00	100.00
16	75.15	71.07
17	55.11	48.20
18	89.38	80.83
19	65.90	47.28
20	100.00	100.00
21	100.00	100.00

Table 3

Comparison of Efficiency Ratings—MACOM #2 and Joint Analysis (FY85)

Installation	MACOM #2	MACOMs #1 & #2
1	100.00	100.00
2	99.89	97.42
3	91.02	87.48
4	100.00	100.00
5	100.00	100.00
6	100.00	100.00
7	79.17	78.66
8	100.00	100.00
9	100.00	100.00
10	79.04	71.97
11	100.00	100.00
12	100.00	100.00
13	100.00	95.91
14	100.00	100.00
15	100.00	100.00
16	90.48	89.65
17	78.17	70.11
18	100.00	100.00
19	62.60	61.87
20	87.74	85.10
21	100.00	100.00

Validation of Results

The results were submitted to prospective users of RPMA resources for validation at two different levels: (1) OCE and (2) the installations. At the headquarters level, the managers agreed that, in the case of MACOM #1, the installations identified by DEA as inefficient were likely to be relatively inefficient, although values of the slacks* associated with the inputs and outputs in some of the cases were viewed as out of range. In addition, the managers thought that the efficiency rate assigned to installation #17 (55.11 percent) was too low and might be due to the geographic location of the installation (Alaska).

Regarding the results for MACOM #2, managers at the headquarters level strongly agreed that installation #19, which was rated at 62.6 percent in FY85, is one of the most efficient installations. In both cases (i.e., MACOM #1 and MACOM #2), the managers agreed that not all of the installations rated as 100 percent efficient could be perceived as equally efficient. In other words, the managers held that the model should be able to differentiate better among efficient installations.

*A geometrical interpretation of the slacks variables, along with their suggested usage by managers, is given in Appendix A.

At the installation level, as might be expected, managers were less receptive of the model's capabilities. From their viewpoint, the model suggests budget reductions since the level of outputs is not under their control. However, the installation managers offered valuable suggestions toward improving the model.

Analysis of the user feedback from both levels reveals that the model should produce better results with the following adjustments:

1. The replacement value, as defined earlier, should be used as O_3, instead of square feet of building, to help account for the variety of building types.

2. Instead of using the inverse of BMAR as an output, BMAR should be considered an input.

3. I_1, I_2, I_3, and I_4 should be aggregated into only one input, I_1 = \$(J+K+L+M).

The advantage of the first recommendation was explained in Chapter 2. To understand how the second recommendation will benefit the model, consider installation #19 and its reference set for the analysis of MACOM #2 in FY85. Table 4 shows the results of evaluating those installations under 10 different criteria. Clearly, installation #19 is less efficient for 9 of the 10 criteria. Only under the criterion BMAR/Ksq ft is installation #19 the most efficient. Note also that the seven criteria under which installation #19 is inefficient are all included in the performance model, whereas BMAR/Ksq ft is not. For this criterion to be included in the performance model, BMAR has to be considered an input. As such, the model would rate installation #19 as 100 percent efficient since no other installation is more efficient under this criterion.

Finally, the third recommendation will improve the quality of the results because the number of 100 percent efficient installations will decrease as aggregation reduces the number of degrees of freedom for the model. In addition, aggregation of the four accounts into only one input (I_1) will avoid the difficulties in explaining the value of the slacks associated with each account.

Table 4

Comparison of Installation #19 With Its Reference Set

Installation	Criteria $K/Ksq ft	$L/Ksq ft	$M/Ksq ft
5	$576.85	$94.6	$248.10
11	$2,432.00	$318.00	$953.33
12	$1,314.19	$200.27	$827.72
18	$1,074.79	$67.55	$424.31
19	$2,075.79	$445.05	$1,478.54
	$(J+K+L+M)/Pop.	$(J+K+L+M)/Ksq ft	$BMAR/Ksq ft
5	$3,061.84	$1,066.90	$2,388.61
11	$268.13	$4,048.67	$800.73
12	$1,577.86	$3,659.35	$679.21
18	$2,204.70	$2,010.55	$1,355.82
19	$2,108.26	$5,152.20	$201.19
	$M/Pop.	$J/Pop.	
5	$712.01	$422.85	
11	$56.07	$20.31	
12	$388.77	$477.75	
18	$465.28	$486.77	
19	$605.01	$471.73	
	O_3/I_5	$J/Btu	
5	5.3432	$0.0023	
11	13.0435	$0.0058	
12	36.1590	$0.0145	
18	9.2885	$0.0081	
19	9.2667	$0.0179	

O_3 = Replacement value
I_5 = Sq ft of shops

4 IMPLICATIONS FOR MANAGEMENT

DEA was next evaluated for use in the following managerial tasks: audit and review of operations, planning, and budgeting, and resources determination and prediction. Results from the previous analysis were applied to this evaluation to study the model from a practical standpoint.

DEA as a Management Audit Tool

The most straightforward use of the DEA results is for auditing to distinguish between relatively efficient and inefficient installations. By doing so, managers can concentrate on those inefficient installations most likely to profit from further analysis.[15] In addition, since the efficient installations are in the reference set of inefficient installations, managers can make comparisons to better understand the source of inefficiency. In comparing an inefficient installation with its reference set, the values of the slacks for inputs and outputs show where the comparison is weaker and by how much. Therefore, by analyzing these values, managers should be able to understand the particulars of the inefficient installation and whether those properties are admissible.

Efficient installations also have to be analyzed since DEA results measure only relative efficiency. The values of the "virtual multipliers" (U_θ, V_ι), provide information about the input and output mixture that rates these installations as 100 percent efficient. Thus, managers have to decide if that mixture is the appropriate one.

Planning and Budgeting With DEA

For managers at installations rated less than 100 percent efficient, there is an immediate way to profit from the performance model results: by planning in such a way as to become more like the units in their reference set (hence, more efficient).

Another possible use of the performance model is in the budgeting process. At the MACOM level, the performance model can be used to simulate the budgets submitted by each installation as if they were real data. For the installations whose budgets are rated as less than 100 percent efficient, MACOM management can "negotiate" an alternative budget based on the budgets of the other installations in their reference set. For the installations whose budgets are rated as 100 percent efficient, MACOM managers should ensure that (1) the budget is appropriate and (2) the installations follow it as closely as possible.

As an example of using the performance model in budgeting, suppose that the requested budget of each installation in MACOM #2 is that shown in Table 5. Table 6

[15] H. D. Sherman, "Data Envelopment Analysis as a New Managerial Audit Methodology--Test and Evaluation," *Auditing: A Journal of Practice and Theory* Vol 4, No. 1 (Fall 1984), pp 35-53.

Table 5

Example Requested Budgets for MACOM #2 Installations

Instal-lation	Population Served	Replacement Value D.C.	Energy Budget	$(J+K+L+M)	BMAR	Msq ft
1	8.904	1.750433	0.693742	54.135	15.19642	0.596
2	46.049	2.893076	1.525868	74.879	14.95708	1.426
3	42.212	2.257709	1.310005	56.891	17.57870	1.575
4	2.265	1.979978	0.099975	6.37	1.141	0.025
5	1.698	0.358625	0.316338	5.199	11.6397	0.912
6	46.233	1.430648	0.716229	61.64	5.3088	0.302
7	15.765	1.62362	0.495335	32.464	11.991	0.449
8	23.874	1.073542	0.615065	35.712	5.517	0.366
9	2.784	0.965905	0.254581	13.458	0.89	0.157
10	12.656	0.695382	0.378755	29.659	3.809	0.362
11	25.503	0.091396	0.08973	6.073	1.2011	0.115
12	25.174	1.251925	0.827437	39.721	8.031	0.327
13	40.012	2.61558	1.346354	60.181	28.54462	1.392
14	15.499	0.753619	0.46455	23.434	9.509921	0.257
15	15.822	0.756672	0.473115	40.136	26.898	0.207
16	19.015	1.08138	0.36737	29.833	1.321	0.242
17	3.807	0.493099	0.132355	12.258	2.29	0.096
18	3.024	1.549681	0.18198	6.667	4.495892	0.357
19	19.702	0.959136	0.519221	41.537	1.622	0.87
20	35.387	2.815029	0.95207	52.144	5.288	1.121
21	47.023	2.796394	0.842773	36.66	2.281	0.651

lists the results of applying the performance model to these requested budgets. The results in terms of installation #1 can be interpreted as follows:

- The budget requested by Installation #1 is only 60.07 percent efficient compared with the budgets requested by the rest of the installations in MACOM #2.
- Installations that had the most influence on installation #1's efficiency rate are 4, 12, and 21 (reference set).

To increase the efficiency of installation #1's budget, management should try to decrease the amount of inputs budgeted. As an example, there are three possible ways of making this installation's requested budget 100 percent efficient:

1. Reduce (J+K+L+M) by 47 percent, or
2. Reduce BMAR by 88 percent, or
3. Reduce (J+K+L+M) and BMAR by 46 percent each.

Table 6

Example Results of Applying Performance Model to Requested Budgets

Unit Evaluated	u1 01 S01	u2 02 S02	u3 03 S03	u4 04 S04	u5 05 S05	v1 11 S11	v2 12 S12	v3 13 S13	v4 14 S14	v5 15 S15	Efficiency
	03 = Raple Value; 11 = J + K + L + M; 12 = BMAR										
1	0.0001 8.904 17.87525	0 0 0	1.161984 1.750433 0	0.0001 0 0	83.65928 0.693742 0	1.578363 54.135 0	0.0001 15.19642 3.967739	0.0001 0 0	0.0001 0 0	24.41909 0.596 0	60.07
REF. SET LAMBDA			21 0.271032		12 0.543307		4 0.157749				
2	0.0001 46.049 16.87386	0 0 0	0.0001 2.893076 0.783687	0.0001 0 0	57.17797 1.525868 0	1.075741 74.879 0	0.027004 14.95708 0	0.0001 0 0	0.0001 0 0	13.35599 1.426 0	87.25
REF. SET LAMBDA			21 0.933828		12 0.725692		5 0.437499				
3	0.0001 42.212 6.059178	0 0 0	0.00010 2.257709 0.707511	0.0001 0 0	69.13114 1.310005 0	1.300607 56.891 0	0302707 17.57870 0	0.0001 0 0	0.0001 0 0	16.14742 1.575 0	90.57
REF. SET LAMBDA			21 0.714590		12 0.524291		5 0.866000				
4	0.0001 2.265 0	0 0 0	10.89597 1.979978 0	0.0001 0 0	784.4559 0.099975 0	14.80019 6037 0	0.0001 1.141 0	0.0001 0 0	0.0001 0 0	228.9046 0.025 0	100.00
REF. SET LAMBDA			0		0		4 1				
5	0.0001 1.698 0	0 0 0	5.268001 0.358625 0	0.0001 0 0	310.1448 0.316338 0	6.213773 5.199 0	0.0001 11.6397 0	0.0001 0 0	0.0001 0 0	74.22525 0.912 0	100.00
REF. SET LAMBDA					5 1		0				
6	0.542710 46.233 0	0 0 0	0.208507 1.430648 0	0.0001 0 0	104.1713 0.716229 0	0.656740 61.64 0	4.199604 5.3088 0	0.0001 0 0	0.0001 0 0	123.2570 0.302 0	100.00
REF. SET LAMBDA			0		0		6 1		0		
7	0.0001 15.765 7.206334	0 0 0	1.86048 1.62362 0	0.0001 0 0	134.4921 0.495335 0	2.537420 32.464 0	0.0001 11.991 5.731581	0.0001 0 0	0.0001 0 0	39.5162 0.449 0	69.65
REF. SET LAMBDA			21 0.375535		12 0.196130		4 0.165625				

Table 6 (Cont'd)

	TRADOC FY85 03 = Reple Value; 11 = J + K + L + M; 12 = BMAR										
Unit Evaluated	u1 01 S01	u2 02 S02	u3 03 S03	u4 04 S04	u5 05 S05	v1 11 S11	v2 12 S12	v3 13 S13	v4 14 S14	v5 15 S15	Efficiency
	0.257102	0	0.0001	0.0001	127.3092	0.498094	5.988697	0.0001	0.0001	134.3508	
8	23.874	0	1.073542	0	0.615065	35.712	5.517	0	0	0.366	84.44
	0	0	0.199341	0	0	0	0	0	0	0	
REF. SET			21		12		9		6		
LAMBDA			0.196586		0.487196		0.045502		0.048422		
	0.776121	0	0.0001	0.0001	384.3145	1.503616	18.07839	0.0001	0.0001	405.5704	
9	2.784	0	0.965905	0	0.254581	13.458	0.89	0	0	0.157	100.00
	0	0	0	0	0	0	0	0	0	0	
REF. SET					9						
			0		1		0				
	0.0001	0	0.0001	0.0001	158.6812	1.396629	4.991440	0.0001	0.0001	109.2955	
10	12.656	0	0.695382	0	0.378755	29.659	3.809	0	0	0.362	60.10
	1.349792	0	0.276506	0	0	0	0	0	0	0	
REF. SET			21		12		9				
LAMBDA			0.171320		0.210027		0.237983				
	2.333557	0	0.0001	0.0001	451.2126	2.825315	18.26630	0.0001	0.0001	529.5844	
11	25.503	0	0.091396	0	0.08973	6.073	1.2011	0	0	0.115	100.00
	0	0	0	0	0	0	0	0	0	0	
REF. SET					11						
LAMBDA			0		1		0				
	0.0001	0	0.0001	0.0001	120.8519	2.273590	0.057384	0.0001	0.0001	28.22579	
12	25.174	0	1.251925	0	0.827437	39.721	8.031	0	0	0.327	100.00
	0	0	0	0	0	0	0	0	0	0	
REF. SET					12						
LAMBDA			0		1		0				
	0.0001	0	0.192206	0.0001	67.83176	1.285122	0.0001	0.0001	0.0001	16.27669	
13	40.012	0	2.61558	0	1.346354	60.181	28.54462	0	0	1.392	91.83
	4.276235	0	0	0	0	0	93148678	0	0	0	
REF. SET			21		12		5				
LAMBDA			0.441035		0.883524		0.770062				
	0.036164	0	0.0001	0.0001	197.5519	3.749458	0.0001	0.0001	0.0001	47.21495	
14	15.499	0	0.756619	0	0.46455	23.434	9.509921	0	0	0.257	92.33
	0	0	0.062790	0	0	0	4.413071	0	0	0	
REF. SET			21		12		5				
LAMBDA			0.077546		0.468334		0.036918				

Table 6 (Cont'd)

TRADOC FY85 03 = Reple Value; 11 = J + K + L + M; 12 = BMAR

Unit Evaluated	u1 01 S01	u2 02 S02	u3 03 S03	u4 04 S04	u5 05 S05	v1 11 S11	v2 12 S12	v3 13 S13	v4 14 S14	v5 15 S15	Efficiency
	0.815016	0	0.0001	0.0001	124.4866	1.454481	0.0001	0.0001	0.0001	201.0639	
15	15.822	0	0.756672	0	0.473115	40.136	26.898	0	0	0.207	71.79
	0	0	6.670216	0	0	0	14.02997	0	0	0	
REF. SET			12		11		4				
LAMBDA			0.107437		0.188012		3.674384				
	0.553984	0	0.0001	0.0001	243.5307	0.329187	18.36124	0.0001	0.0001	272.4137	
16	19.015	0	1.08138	0	0.36737	29.833	1.321	0	0	0.242	100.00
	0	0	0	0	0	0	0	0	0	0	
REF. SET					16						
LAMBDA			0		1						
	0.787592	0	0.089840	0.0001	388.9194	1.523901	18.28649	0.0001	0.0001	410.8745	
17	3.807	0	0.493099	0	0.132355	12.258	2.29	0	0	0.096	54.52
	0	0	0	0	0	0	0	0	0	0	
REF. SET			21		12		9		6		4
LAMBDA			0.000677		0.129031		0.034201		0.002070		0.148319
	1.647673	0	19.77517	0.0001	353.7323	11.36288	5.049253	0.0001	0.0001	4.321458	
18	3.024	0	1.549681	0	0.18198	6.667	4.495892	0	0	0.357	100.00
	0	0	0	0	0	0	0	0	0	0	
REF. SET					18						
LAMBDA			0				0		0		
	0.0001	0	0.0001	0.0001	166.8558	0.0001	61.64966	0.0001	0.0001	0.0001	
19	19.702	0	0.959136	0	0.519221	41.537	1.622	0	0	0.87	86.64
	9.268231	0	0.763684	0	0	13.40173	0	0	0	0.352691	
REF. SET			21								
LAMBDA			0.616086								
	0.0001	0	0.0001	0.0001	81001345	1.774876	1.408985	0.0001	0.0001	0.0001	
20	35.387	0	2.815029	0	0.95207	52.144	50288	0	0	1.121	77.13
	15.51216	0	0.247765	0	0	0	0	0	0	0.352691	
REF. SET			21		5						
LAMBDA			1.077401		0.139298						
	0.0001	0	0.0001	0.0004	118.6500	2.599370	2.063581	0.0001	0.0001	0.0001	
21	47.023	0	2.796394	0	0.842773	36.66	2.281	0	0	0.651	100.00
	0	0	0	0	0	0	0	0	0	0	
REF. SET			21								
LAMBDA			1		0						

Resource Determination With DEA

One of the most attractive features of DEA is its ability to identify the efficiency frontier, which allows managers to know if a "production possibility"* will be relatively efficient compared with the rest of the DMU. This property of DEA can be exploited further by managers when trying to predict the level of resources (inputs) needed to reach a specific level of outputs in the future.

The above problem can be approached using DEA as follows:

Let $\bar{O}_d = (O_{1d},\ldots,O_{sd})$ be the known level of outputs that installation d wants to produce next year.

Let $\bar{I}_d = (I_{1d},\ldots,I_{md})$ be the unknown input vector necessary for installation d to produce $\bar{O}_d$ next year.

Let $\bar{I}_g = (I_{1g},\ldots,I_{mg})$ be an estimated input vector for installation d. In other words, $\bar{I}_g$ is an input vector with which management "feels" confident to produce $\bar{O}_d$ next year in installation d. Then:

Let DMU_D be a dummy DMU with its input-output vector represented by $(\bar{O}_d, \bar{I}_g)$.

Now DMU_D can be added to the set of installations, DMU_j; j=1,...,n, and the efficiency of DMU_D can be evaluated with respect to the extended set of installations, DMU_j; j=1,...,n,D.

Suppose that DMU_D is rated as less than 100 percent efficient. Then, projecting $(\bar{O}_d, \bar{I}_g)$ into the efficiency frontier[16] will make DMU_D 100 percent efficient. In other words, the input vector $\bar{I}_d = \Theta \cdot \bar{I}_g - \bar{S}_i$ will be enough to produce $\bar{O}_d$ next year if DMU_D operates efficiently.

Observe that the production possibility represented by $(\bar{O}_d, \bar{I}_d)$ is the efficiency frontier point "closest" to $(\bar{O}_d, \bar{I}_g)$. Here, "close" means similar in production technology or input-mix. Thus, the problem being addressed has several different solutions, each depending on the input-mix (recipe) to be used to produce $\bar{O}_d$.

Since the value I_d, as determined above, depends on the value $\bar{I}_g$ seeded, the process can be repeated several times to explore the various alternatives in input-mix for DMU_D to produce $\bar{O}_d$. Managers will be responsible for deciding which $\bar{I}_d$ (input-mix) DMU_D should use the following year to produce $\bar{O}_d$.

---

*Feasible set of inputs and output values.

[16]A. Charnes and W. W. Cooper, "The Non-Archimedean CCR ratio for Efficiency Analysis: A Rejoinder to Boyd and Fare," *European Journal of Operational Research*, Vol 15 (1984), pp 333-334.

To continue the example, suppose now that the data in Table 5 are the real data corresponding to the installations in MACOM #2 for FY86. Then, Table 6 now contains the results of evaluating the installation's performance during FY86. In other words, now the interpretation of results regarding installation #1 is:

- The efficiency rate assigned to installation #1 in FY86 is 60.07 percent.
- Installations with the most influence on installation #1's efficiency rate are 4, 12, and 21.

Suppose also that the managers want to know how much (J+K+L+M)--I_1--will cost to operate installation #1 in 1990 assuming that: (1) O_1, O_3, O_5, and I_5 will remain at the same level as that in 1986, (2) O_2 will increase 10 percent with respect to the 1986 level, and (3) I_2 (BMAR) will not exceed \$5 million. To solve this problem, the managers proceed as explained earlier:

1. Create a dummy DMU for installation #1 - with: O_1 = 8.904, O_3 = 1.925476, O_5 = 0.693742, I_1 = dummy = 54.135, I_2 = 5 and I_5 = 0.596.

2. Add the above dummy DMU to the set of installations in Table 5 and apply DEA to the new set. The efficiency rate of the dummy DMU is then 66.43 percent (Table 7).

3. Decrease the value of I_1 in dummy DMU until its efficiency rate equals 100 percent (Table 7). The value of I_1 that makes the dummy DMU's efficiency rate 100 percent is I_3 = 29.31139. This figure will be the cost to operate installation #1 efficiently in 1990 assuming 1986 prices do not change.

One more issue should be addressed under this discussion--the reallocation of resources among efficient DMUs. Here, the question is "Which DMU will have the greatest potential to use additional resources," or, "Which DMUs are underfunded, and by how much." The answer to these questions requires a deeper analysis of the efficiency frontier.

At first glance, the underfunded installations, if any, must be among the units rated 100 percent efficient by DEA. As a general rule of thumb, resources should be reallocated from inefficient units to relatively efficient ones. However, the efficiency frontier must be studied closely since DEA does not differentiate among relatively efficient installations. One way to further differentiate among relatively efficient installations using DEA is by seeding a small number of "utopian" installations into the set of DMUs (utopian in the context of efficiency). By doing so, only the fictitious installations will be rated relatively efficient, and the rest of the DMUs (DMU = j; j = 1,...,n) will be evaluated against them.

The main drawback to this approach is that the utopian installations do not belong to the production possibility set; hence, the new efficiency rate of the real installation may be unrealistic. However, this problem can be alleviated by selecting the utopian DMU to be as realistic as possible.

Table 7

Resource Determination With DEA

	U_1	U_3	U_5	V_1	V_2	V_5
	O_1	O_3	O_5	I_1	I_2	I_5
	S_1^-	S_3^-	S_5^-	S_1^+	S_2^+	S_5^+
	0.0001	0.0001	95.76124	0.842747	3.012537	65.96505
Dummy #1	8.904	1.925476	0.693742	54.135	5	0
	1.532	0.376766	0	0	0	0
REF.SET	21	12	9			
LAMBDA	0.000907	0.174583	2.154602			
Decreasing I_2						
	0.0001	0.351734	123.5046	2.339895	0.0001	29.63733
Dummy #1	8.904	1.925476	0.693767	35.18775	5	0.596
	24.07107	0	0	0	0.406969	0
REF.SET	21	12	5			
LAMBDA	0.581312	0.219265	0.07808			
Further Decreasing I_2						
	0.005986	0.323894	143.1764	2.713590	0.0001	34.32949
Dummy #2	8.904	1.925476	0.693742	29.31139	5	0.596
	0	0	0	0	0	0
REF.SET	Dummy #1					
LAMBDA	1					

O_1 = Population served
O_3 = Replacement value
O_5 = Btu/yr.
I_1 = \$ (J+K+L+M)
I_2 = \$BMAR
I_5 = Sq ft of shops

5 CONCLUSIONS AND RECOMMENDATIONS

Three modeling techniques have been studied for potential in providing an output-oriented performance index to evaluate the efficiency of RPMA programs at U.S. Army installations. The methodology chosen for further evaluation was DEA because of its ability to handle multiple inputs and outputs simultaneously and without requiring *a priori* specification of weight or functional relationships among these parameters. These features make DEA suitable for application to not-for-profit organizations such as Army installations.

The DEA proccess was analyzed, and it was concluded that:

1. DMUs identified as inefficient by DEA were strictly inefficient compared with other existing DMUs.

2. DEA can associate a narrow set of relatively efficient units (the reference set) with the inefficient unit under evaluation, which helps managers identify the source of inefficiency.

3. DEA identifies an efficiency frontier consisting of relatively efficient DMUs, which means this frontier is a practically attainable production possibility set.

4. DEA does not necessarily locate all inefficient units; thus, some units rated as relatively efficient may be strictly inefficient.

5. DEA identifies alternative paths for making inefficient DMUs become relatively efficient.

6. The choice of input and output measures used is critical to the inherent value of the results.

Input and output measures were selected to fully exploit the capabilities of DEA for the user. A compromise was reached between the desired data and that which was available. Numerical results of the analysis were presented to a panel of managers for validation. These managers suggested that the model should further differentiate between the installations rated as 100 percent efficient.

This study has shown that DEA is a theoretically sound technique capable of evaluating the performance of RPMA at Army installations. Optimal use of DEA will be possible once the method is "fine-tuned" by testing alternative input and output measures until its capabilities are fully exploited.

Based on these findings, it is recommended that a prototype of the performance model be implemented within OORMS to allow prospective users to test alternative input and output measures.

REFERENCES

Banker, R. D., R. F. Conrad, and R. P. Strauss, "A Comparative Application of Data Envelopment Analysis and Translog Methods: An Illustrative Study of Hospital Production," *Management Science*, Vol 32, No. 1 (January 1986).

Bessent, A., and W. Bessent, "Determining the Comparative Efficiency of Schools Through Data Envelopment Analysis," *Educational Administrative Quarterly*, Vol 16, No. 2 (1980).

Bessent, A., W. Bessent, A. Charnes, W. W. Cooper, and N. Thorogood, "Evaluation of Educational Program Proposals by Means of DEA," *Educational Administrative Quarterly*, Vol 19, No. 2 (Spring 1983).

Bessent, A., W. Bessent, C. T. Clark, and J. Elam, "Constrained Facet Analysis, A New Method for Evaluating Local Frontiers of Efficiency and Performance," *Air Force Journal of Logistics* (Summer 1984).

Bowlin, W. F., A. Charnes, W. W. Cooper, and H. D. Sherman, *A Comparative Study of Data Envelopment Analysis and Other Approaches to Efficiency Estimation*, Research Report CCS 451 (Center for Cybernetic Studies, The University of Texas at Austin, September 1983).

Bowlin, W. F., *A Data Envelopment Analysis Approach to Performance Evaluation in Not-for-Profit Entities With an Illustrative Application to the U. S. Air Force*, Ph.D. dissertation (The University of Texas at Austin, December 1984).

Bowlin, W. F., *Report on Evaluating the Efficiency of Real Property Maintenance Activities in the Air Training Command* (Air Force Institute of Technology, Wright-Patterson AFB, OH, November 1984).

Charnes, A., and W. W. Cooper, "The Non-Archimedean CCR Ratio for Efficiency Analysis: A Rejoinder to Boyd and Fare," *European Journal of Operational Research*, Vol 15 (1984).

Charnes, A., and W. W. Cooper, "Preface to Topics in Data Envelopment Analysis," *Annals of Operations Research*, Vol 2 (1985).

Charnes, A., and W. W. Cooper, "Programming With Linear Fractional Functionals," *Naval Research Logistics Quarterly*, Vol 9 (1962).

Charnes, A., W. W. Cooper, and E. Rhodes, "Evaluating Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through," *Management Science*, Vol 27, No. 6 (1981).

Charnes, A., W. W. Cooper, and E. Rhodes, "Measuring the Efficiency of Decision-Making Units," *European Journal of Operational Research*, Vol 2, No. 6 (November 1978).

Charnes, A., W. W. Cooper, and E. Rhodes, "Short Communication: Measuring the Efficiency of Decision-Making Units," *European Journal of Operational Research* (1979).

Clark, C. T., *Data Envelopment Analysis and Extensions for Decision Support and Management Planning*, Ph.D. dissertation (The University of Texas at Austin, May 1983).

Coskunoglu, O., "Appraisal of Army"s Facilities," RPMA Information Paper No. 37 (U.S. Army Construction Engineering Research Laboratory, November 1985).

Design Criteria, Architectural and Engineering Instructions (OCE, Engineering Division, 13 March 1987). Available through PAXMAIL.

Lewis, A., and R. C. Morey, "Measuring the Relative Efficiency and Output Potential of Public Sector Organizations: An Application of Data Envelopment Analysis," *International Journal of Policy Analysis and Information Systems*, Vol 5, No. 4 (December 1981).

Output Oriented Resource Management System, Handbook (Office of the Comptroller of the Army, June 1986).

Real Property Management Activities (RPMA), Executive Summary, Vol 1 (Department of the Army Study Group, March 1978).

Sherman, H. D., "Data Envelopment Analysis as a New Managerial Audit Methodology--Test and Evaluation," *Auditing: A Journal of Practice and Theory*, Vol 4, No. 1 (Fall 1984), pp 35-53.

Sherman, H. D., *Measurement of Hospital Efficiency Using Data Envelopment Analysis*, unpublished DBA thesis (Graduate School of Business, Harvard University, 1981).

APPENDIX A:

DATA ENVELOPMENT ANALYSIS—CONCEPT AND DERIVATION

This appendix describes the fundamentals of DEA. The first section focuses on mathematical formulation of the model, with the second part summarizing the model's strengths and weaknesses.

Linear Programming Formulation

The formulation in the text designated as Equation 2 is an extended nonlinear programming formulation of an ordinary fractional programming problem. However, studies[17] have shown that it can be transformed into an equivalent linear programming problem using the theory of linear fractional programming developed by Charnes and Cooper as follows:[18]

Maximize: $$h_{jo} = \sum_{r=1}^{s} U_r O_{rjo}$$

Subject to: $$\sum_{i=1}^{m} V_i I_{ijo} = 1$$

$$\sum_{r=1}^{s} U_r O_{rj} - \sum_{i=1}^{m} V_i I_{ij} \leq 0; \; j = 1, .., jo, .., n$$

$$U_r \geq \varepsilon > o \quad r = 1, .., s$$

$$V_i \geq \varepsilon > 0 \quad i = 1, .., m \qquad \text{[Eq A1]}$$

The Equation A1 formulation constrains the weighted sum of the inputs to be equal to 1 and maximizes the outputs that can be obtained. The other constraints in Equation A1 transform the less-than-unity constraints of Equation 2 (Chapter 2) to a form in which the weighted output cannot exceed the weighted input for any DMU. Equation A1 is also called the "unit input" formulation.

---

[17] A. Charnes, W. W. Cooper, and E. Rhodes (1978); A. Charnes, W. W. Cooper, and E. Rhodes (1979).

[18] A. Charnes and W. W. Cooper.

The dual linear program of Equation A1 can be written as follows:

Minimize: $$[\theta - \varepsilon (\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+)]$$

Subject to: $$\sum_{j=1}^{n} \lambda_j O_{rj} - S_r^+ = O_{rjo} \qquad r = 1, .., s$$

$$-\sum_{j=1}^{n} \lambda_j I_{ij} - S_i^- + \theta I_{ijo} = 0 \qquad i = 1, .., m$$

$$\lambda_j, S_r^+, S_j^- \geq 0 \text{ and } \theta \text{ unrestricted in sign} \qquad \text{[Eq A2]}$$

Where:

θ = An intensity value or multiplier of the observed input vector x_{io}
S_r^- = output slack for output "r"
S_i^+ = input slack for input "i"
ε = A small non-Archimedean constant.

In Equation A2, the variable θ is considered an "intensity" variable that reduces the value of all inputs to the smallest number permitted by the constraints. The variables λ_j ; j=1,..,n are the dual variables associated with the constraints representing DMU_j; j=1,..,n in Equation A1. For λ_j to be positive (>0), its corresponding DMU_j constraint in Equation A1 has to be equal to 0, which means that DMU_j is in the reference set of the DMU being evaluated, DMU_{jo}.

The name "data envelopment analysis" comes from the facts that, in Equation A2: (1) the linear combination of output vectors represented by the $\lambda_j O_{rj}$ envelops the observed output vector of the DMU being evaluated from above, and (2) the same linear combination, but with the input vectors, envelops the "minimum" vector of observed inputs from below.

The presence of the non-Archimedean constant in the objective function of Equation A2 is equivalent to a double optimization since ε is so small that $\varepsilon (\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+)]$ does not affect the value of θ. In other words, two optimizations occur at the same time: (1) minimize θ and (2) maximize $(\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+)$.

By virtue of the duality theory of linear programming:

$$\text{Maximize } h_{jo} = \sum_{r=1}^{s} U_r O_{rjo} = \text{Minimize } [\theta - \varepsilon (\sum_{i=1}^{s} S_r^- + \sum_{r=1}^{s} S_r^+)] \qquad \text{[Eq A3]}$$

Also note that S_r^+ and S_i^- are the dual variables associated with the constraints $U_r \geq \varepsilon$, $V_i \geq \varepsilon$ in Equation A2, respectively; therefore, at optimality, the only time the corresponding $U_r = \varepsilon$ and/or $V_i = \varepsilon$ is when $S_i^- \geq 0$ and/or $S_r^+ \geq 0$.

From the above discussion, it can be shown that a DMU is considered efficient if and only if $\theta^* = 1$, and all S_i^{-*} and S_r^{+*} are equal to zero in Equation A3. This reasoning is called the non-Archimedean efficiency theorem for which formal proof can be found elsewhere.[19]

Efficiency Adjustments and Projections

In addition to measuring the relative efficiency of a DMU, DEA provides additional information for the inefficient DMU to become efficient. Let θ^*, λ_j^*, S_i^{-*}, S_r^{+*} be an optimal solution of Equation A2 for DMU_{jo}. Then, Equation A2 can be rewritten as:

$$\theta^* I_{io} - S_i^{-*} = \sum_{j=1}^{n} I_{ij}\lambda_j^* \quad i=1, .., m \qquad \text{[Eq A4]}$$

$$O_{ro} + S_r^{+*} = \sum_{j=1}^{m} O_{rj}\lambda_j^* \quad r=1, .., s$$

If the left-hand side of Equation A4 is replaced with Equation A5:

$$I'_{io} = \theta^* I_{io} - S_i^{-*} \quad i=1, .., m$$

$$O'_{ro} = O_{ro} + S_r^{+*} \quad r=1, .., s$$

then a DMU with its production vector represented by the new values $(\bar{O}'_j, \bar{I}'_j)$ will be rated efficient, relative to the same set DMU_j; j=1,...,n, since $\theta'^* = 1$, $S_r^{+*} = 0$ and $e_i^* = 0$ will be an optimal solution of Equation A2. (Formal proof of this derivation is shown elsewhere.[20]) Thus, the transformation (Eq A5) projects DMU_{jo} into its reference set, and the values S_i^*, S_r^{+*} and θ^* represent the adjustments needed for DMU_{jo} to become efficient.

To better explain the Charnes, et al. formulation, it can be applied to a simple problem with a simple geometrical solution. Consider a set of four DMUs each with two inputs, I_1 and I_2, and one output, O_1. To simplify, assume that O_1 is equal to 1 for the four DMU's. Figure A1 represents the four DMUs by their coordinate values for I_1 and I_2. For example, P_1 has $I_{11} = 2$, $I_{21} = 2$, $O_{11} = 1$; P_2 has $I_{12} = 3$, $I_{22} = 2$, $O_{12} = 1$; and so on.

[19]A. Charnes and W. W. Cooper, "Preface to Topics in Data Envelopment Analysis," *Annals of Operations Research*, Vol 2 (1985), pp 59-94.
[20]A. Charnes and W. W. Cooper (1985).

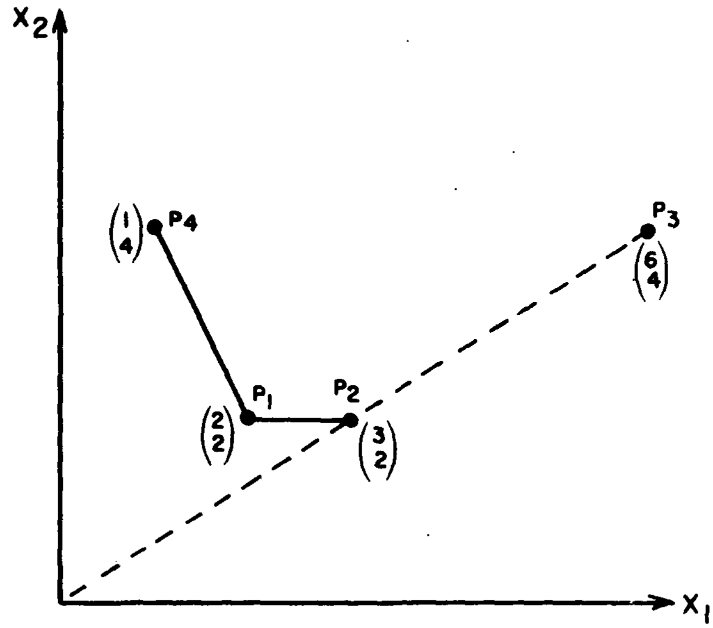

Figure A1. Example problem with a simple geometrical solution.

To evaluate P_2, its coordinates are inserted into Equation A3 to obtain:

Minimize: $$\theta - \varepsilon S_1^- - \varepsilon S_2^- - \varepsilon S_1^+$$

Subject to:

$$3\theta = 2\lambda_1 + 3\lambda_2 + 1\lambda_3 + 6\lambda_4 + S_1^-$$

$$2\theta = 2\lambda_1 + 2\lambda_2 + 4\lambda_3 + 4\lambda_4 + S_2^-$$

$$1 + S_1^+ = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4$$

for which the solution is:

$$\theta^* = 1,\ S_1^{-*} = 1,\ \lambda_1^{\ *} = 1 \text{ and}$$

$$S_2^{-*} = S_1^{+*} = \lambda_2^{\ *} = \lambda_3^{\ *} = \lambda_4^{\ *} = 0$$

Although $\theta^* = 1$, DMU P_2 is not fully efficient since $S_1^{\ *}$ equals 1. The fact that $\lambda_1 = 1$ means that P_2 is being evaluated against P_1. Moreover, the value of $S_1^{-*} = 1$ means that, when comparing P_2 with P_1, P_2 uses one more unit of input 1 than does P_1 to produce the same amount of output. In other words, P_1 produces the same amount of output as P_2, but with one unit less of input, I_1, and the same amount of I_2.

For P_2 to be as efficient as P_1, it has to reduce I_1 by one unit, which produces the same result as if the transformation (Eq A5) had been applied.

The solution of Equation A3 for P_1 is:

$$\theta^* = 1, \; S_1^{-*} = S_2^{-*} = S_1^{+*} = 0, \; \lambda_1^* = 1$$

$$\lambda_2^* = \lambda_3^* = \lambda_4^* = \phi$$

which means that P_1 is fully efficient, and also that it is evaluated against itself, ($\lambda_1^* = 1$). Thus, no other DMU is more efficient than P_1.

In the same way, the result of evaluating P_4 is:

$$\theta^* = 1, \; S_1^{-*} = S_2^{-*} = S_1^{+*} = 0, \; \lambda_4^* = 1$$

$$\lambda_2^* = \lambda_3^* = \lambda_1^*$$

which means that P_4 is fully efficient, and no other DMU is more efficient than P_4, ($\lambda_4^* = 1$).

Referring to Figure A1, the solid line connecting P_4, P_1, and P_2 is called the "efficiency frontier" and is made up of convex combinations of DMU with the efficiency rate equal to 1, ($\theta^* = 1$). Note that, although P_2 is a frontier point, it is not DEA efficient because ($S_1^* = 1$). A point such as P_2 is called, in DEA jargon, a "corner point" of the efficiency frontier.

Similarly, the result of evaluating P_3 is:

$$\theta^* = 1/2 \; S_1^{-*} = 1, \; \lambda_1^* = 1 \quad \text{and}$$

$$S_2^{-*} = S_1^{+*} = \lambda_2^* = \lambda_3^* = \lambda_4^* = 0$$

which is to say that P_3 is being evaluated against $P = 1$ ($\lambda_1^* = 1$). The value of $\theta^* = 1/2$ represents the ratio of the Euclidean distance from the origin to P_3. For P_3 to be as efficient as P_1, it has to reduce its inputs in accordance with Equation A5 as follows:

$$I_{13} = 6 \times 1/2 - 1 = 2$$
$$I_{23} = 4 \times 1/2 = 2$$

The reduction in inputs represented by $\theta^* I_{io}$ bring P_3 to P_2. This reduction is a contraction in which the mix of inputs (technology) does not change. The reduction in input represented by S_i^*, on the contrary, requires a change in input mix, which brings P_3 from P_2 to P_1, and it does not increase the efficiency rate, θ^*. Consequently, the contraction represented by $\theta^* I_{io}$ projects the inefficient unit into the efficiency frontier, whereas the reduction represented by S_1^* brings the inefficient unit into the so-called DEA efficiency region.

DEA Properites and Interpretations

Properties and interpretations of the DEA model above are summarized below.

Relative Efficiency

One hundred percent relative efficiency is attained by any DMU only when comparison with other relevant DMUs provides no evidence of inefficiency in the use of any input or output.

Weights

DEA does not require *a priori* determination of weight to compute efficiency.

Efficiency Rating (θ^*)

The efficiency rating assigned by DEA is the best possible value attainable by the DMU being evaluated. The efficiency rating does not depend on the units in which the inputs and outputs are measured.

Reference Set

DEA also provides the relatively inefficient units with a set of relatively efficient units that have a "similar" input/output mix.

Efficiency Frontier

The efficiency frontier consists of a piecewise linear combination of the efficient units, which means that it is practically attainable since it is in the production possibility set.

Efficiency Improvement

V_i^* and U_r^* are the dual variables of Equation A2, representing the marginal gain in efficiency if one less unit of the ith resource is used or one more unit of the rth output is produced.

The transformation (Eq A5) that makes an inefficient unit DEA efficient can be seen as a two-stage process:

1. The reduction of I_i to $\theta^* \ I_{io}$ increases the efficiency rate to 1 without changing the input mix ("recipe").

2. $S_i^{\theta *}$ and S_r^{+*} represent the additional marginal improvements possible for the unit to become truly efficient.

Production Process

The DEA model assumes that each input has some relationship to one or more outputs, but it is not necessary to specify these functional relationships explicitly.

APPENDIX B:

EXPLANATION OF COMPUTER OUTPUT

Table B1 contains the FY85 computer output for the 21 installations of MACOM #1. For each installation, there are five lines, of which the first three lines contain the values of the weight, slack, and input/output as follows:

Column 1: Name of the installation.

Columns 2-6: Output-related values (note that O_2 is missing because of data unavailability). For the installation, there are three numbers under each of these columns. Consider for example, column 2 (Output-1: Population Served) of row 1 (installation #1):

1. First number (u_1) = 0.001163. This is the weight assigned to output O_1 (population size) installation #1.

2. Second number (O_1) = 50.79. This is the value of output O_1 for installation #1. That is, the population of installation #1 is 50,790.

3. Third number (SO_1) = 0. This is the slack in output 1. To illustrate this value, consider installation #5 which has 5.065528 thousand slack. Thus, using the current resources, installation #5 could serve roughly 5065 additional people. (Appendix A gives details.)

Columns 7-11: Input-related values. For example, column 7 (Input 2: K account) of row 1 has three numbers:

1. V_2 = 0: the weight assigned to K account by installation #1.

2. I_2 = 19.11532: the amount of funds (in millions of dollars) received by installation #1 under K account.

3. SI_2 = 0: Slack (inefficiently used) money by installation K under K account.

Column 12: Efficiency rating (performance) of the installation. This efficiency rating is relative to other installations in the reference set.

In addition, the reference set of each inefficient installation and its corresponding λ_i values (as described in Appendix A) are reported in the two lines named REF. SET. and LAMBDA.

Tables B2 and B3 contain the results for MACOM #1 for FY84 and FY83, respectively. Table B4 contains the results for MACOM #2 for FY85; Table B5 lists results of the joint analysis for MACOMs #1 and #2 in FY85.

Table B1

DEA Results for MACOM #1, FY85

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY
1	0 016585	0	4 207306	0 000417	0 0001	0 347802	0 0001	6 569159	3 556382	14 00879	
	50 79	0	23 565	29 51768	1 575665	29 63011	19 11532	5 819449	7 935924	1.659	100 00
	0	0	0	0	0	0	0	0	0	0	
REF SET		1									
LAMBDA		1									
2	0 143052	0	0 098689	0 000580	71 91345	1 749086	0.0001	0 0001	5 803910	15 08883	
	41 295	0	17 408	252 0161	1 282491	17 84937	36.65980	4.617007	7 794262	1 56	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		2									
LAMBDA		1									
3	0 799051	0	0 0001	0 000652	38 83414	0.685267	0.0001	0 0001	6.106295	19 90893	
	80.687	0	11 254	57.58146	0.91384	12 20430	19.50505	2 450487	10.11598	1.5	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		3									
LAMBDA		1									
4	0 862162	0	0.0001	0.000967	122.3930	0 0001	0.0001	15.95779	7.406007	57.44602	
	15.132	0	9 346	488 8780	0.706575	10.41356	15.18643	0.322458	6.229739	0.848	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		4									
LAMBDA		1									
5	0 0001	0	0.0001	0 000534	144.4227	5.835199	0.0001	0.0001	4.700293	42.75963	
	11.526	0	8 3	294 8113	0.657605	7 96222	13.61274	2.518795	5.347827	0.662	95.13
	5 065528	0	1 215179	0	0	0	0.238690	0.534784	0	0	
REF SET		21		20		15		10			
LAMBDA		0.234959		0 262236		0.002916		0.253098			
6	0 257749	0	3 289438	0 0001	0.0001	1 698690	0.735384	0 0001	3.303908	0.0001	
	64 404	0	23.449	9.333843	1.617933	22.45047	32.50205	5.276858	11.48981	2 353	93 74
	0	0	0	154 8502	0.004533	0	0	0.830328	0	0.157584	
REF SET		21		14		12		1			
LAMBDA		0 355275		0 502962		0.595485		0.151788			
7	0.782865	0	5 584307	0.0001	0 0001	2.475819	0.0001	11.28350	0.0001	45.43333	
	25 594	0	12 144	85 10421	0 757919	11 68280	25.82272	3 37932	8.959907	0 725	87 86
	0	0	0	166 1466	0.060425	0	2.860670	0	0.148389	0	
REF SET		20		14		10		3			
LAMBDA		0 242792		0 264293		1 148736		0 050068			

Table B1 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY
8	0 181236	0	3 898770	0 0001	0.0001	1 703138	0.0001	0.0001	6 378057	0.0001	
	44 363	0	23 357	23 90834	1 594364	18 18247	39 80743	4 909878	10 82273	2.272	99 11
	0	0	0	80 71090	0 032691	0	9 237421	1.063930	0	0 135376	
REF SET		21		14		1					
LAMBDA		1 180930		0 071652		0 193001					
9	0 906749	0	11 27665	0.0001	0 0001	6 442170	5 568521	0.0001	1 822634	0.0001	
	5 292	0	8 441	151 4646	0 711375	5 710307	8 190885	1 942642	9 657363	0 692	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		9									
LAMBDA		1									
10	2 253386	0	24 12789	0 000262	0 0001	20 10938	4 372766	0 0001	0 0001	93 90097	
	4 511	0	3 722	118.0038	0 23854	2 544618	8.825912	1.158742	3.192209	0.109	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		10									
LAMBDA		1									
11	0 940763	0	5 477403	0.000213	0.0001	2.058142	0.0001	11.44087	0.0001	57.34621	
	45 64	0	10.245	162 3534	0.688226	21.44733	17.02951	2.255635	7.782973	0.524	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		11									
LAMBDA		1									
12	0.659232	0	4 300580	0.000192	2.343146	1.338466	0.0001	10.90373	0.303024	38 41366	
	51 64	0	14.766	55.56296	1.043105	13 50181	20.31280	2.326554	7.268419	1.415	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		12									
LAMBDA		1									
13	0 0001	0	0.0001	0.000801	216.5823	8.750568	0.0001	0.0001	7.048908	64 12358	
	6 826	0	4.366	211.6446	0 320895	5 391996	9.773071	1.503468	3.890375	0.396	69 67
	1 057828	0	0 324703	0	0	0	0.052148	0.041304	0	0	
REF SET		21		20		15		10			
LAMBDA		0 091569		0.129564		0 002277		0.262272			
14	0 694697	0	0.0001	0.000370	102.4431	5.182226	0.0001	0.0001	3.269580	36.60228	
	32.294	0	11 26	201.1950	0.756418	9.988661	15.56383	2.164391	5.136244	0.859	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		14									
LAMBDA		1									

Table B1 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY
15	1 271009	0	0 0001	0 000677	187 4340	9 481449	0.0001	0.0001	5.982411	66.96858	
	7 943	0	3 73	62500	0.253815	3 0026	6.6038	1.2107	7.7813	0 373	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		15									
LAMBDA		1									
16	0 974420	0	0 0001	0 000172	105.7161	5 307160	1.093490	0.0001	0.0001	59.42778	
	14 305	0	7.798	231 4707	0 578615	9 273363	16.27916	3.156487	9.357042	0.555	75 15
	0	0	0 487683	0	0	0	0	0.320220	1.189386	0	
REF SET		20		15		10		9		3	
LAMBDA		0 249704		0 001147		0.671121		0.114734		0.032234	
17	0 0001	0	0 0001	0 001414	403.7585	0 0001	0.0001	50.55034	0.0001	347 7439	
	2 099	0	1 551	2531.645	0 12763	4 329493	4.826782	0.822503	2.962144	0.168	55.11
	1 156669	0	0.322937	0	0	0 716257	0 158706	0	0.338642	0	
REF SET		20		15		10					
LAMBDA		0 079430		0.040037		0.082847					
18	0 837165	0	0.0001	0 000240	133.3658	4 757292	0.0001	14.24013	0.0001	64.32050	
	12 813	0	7.272	201 8163	0.58935	6.40662	17.01283	1.891752	11.47715	0.662	89.37
	0	0	0.074926	0	0	0	6.724891	0	3.015379	0	
REF SET		20		15		10		9		3	
LAMBDA		0 072967		0 001336		0 090696		0.558660		0.087763	
19	1 613793	0	0.0001	0.0001	35.81589	2 408938	0.0001	0.0001	0.0001	89.03093	
	28 837	0	6 261	85 79787	0 540095	12.42371	25.14478	5.071001	16.45796	0.787	65.89
	0	0	1.423332	68 81568	0	0	0.931073	1.310716	4 283523	0	
REF SET		11		10		3					
LAMBDA		0 132701		1 017661		0 225436					
20	1 046520	0	0.0001	0 0001	53 81195	1 832372	0 650788	0.0001	0 0001	65 71018	
	32 279	0	17.83	245 6338	1.23008	16 85609	18.95926	3.888255	9 038273	0.864	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		20									
LAMBDA		1									
21	0 582329	0	4 708750	0.0001	11.45938	3.718071	0.480231	5.251387	0.0001	28.56240	
	27 306	0	15 244	71 55891	1 074365	9 811973	21 51981	2 137524	7.474892	1.469	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET		21									
LAMBDA		1									

Table B2

DEA Results for MACOM #1, FY84

UNIT EVALUATED	u1 O1 SO1	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY	REFERENCE SET
1	0.004784	0.025321	0.000003	0	0.011133	0.015798	0	0.028433	0		1,3,8,9,15,
	48.758	30.276	20.71997	2.116645	34.95897	22.17873	3.835888	9.158269	1.612	100.00%	
	0	0	0	0	0	0	0	0	0		
2	0.004286	0	0.000002	0.533201	0.015920	0	0	0.025998	0.336838		1,8,9,15,20,
	40.625	17.309	413.7018	1.275213	17.72705	30.09883	5.072391	8.044555	1.51	85.53%	
	0	0.559437	0	0	0	7.519214	2.194052	0	0		
3	0.007686	0.036647	0.000001	0	0.012630	0.008921	0.048426	0	0.408913		1,3,8,11,15,20,
	76.572	11.225	57.58146	0.913455	11.07796	14.41234	2.008648	10.54400	1.551	100.00%	
	0	0	0	0	0	0	0	0	0		
4	0.007102	0	0.000004	0.883440	0.026378	0	0	0.043076	0.558093		1,8,9,15,20,
	17.677	9.349	140.4297	0.70525	10.87770	13.68061	2.287025	6.05922	0.81	74.93%	
	0	0.361455	0	0	0	1.180233	0.160291	0	0		
5	0.015892	0	0	1.458445	0.076848	0	0	0	1.161383		8,9,20,
	6.02	5.681	73.47538	0.461375	4.534417	6.906534	0.809588	3.774354	0.561	76.86%	
	0	0.083980	13.88874	0	0	1.109971	0.033531	0.156441	0		
6	0.001091	0.030688	0	0	0.014425	0	0	0.018165	0.193343		1,8,9,20,
	60.928	23.697	8.162185	1.627175	22.14366	35.78067	4.73625	12.65534	2.331	79.37%	
	0	0	120.3795	0.065660	0	1.214141	0.776719	0	0		
7	0.011723	0.061213	0.000006	0	0	0	0.356083	0	0.657028		1,8,11,15,
	21.397	12.048	83.21821	0.751005	18.37996	19.01707	1.603445	7.511523	0.653	98.89%	
	0	0	0	0.089754	3.818083	9.395996	0	3.350508	0		
8	0.004555	0.031013	0.000001	0	0.009725	0	0.054490	0	0.379704		1,8,11,15,20,
	74.426	21.311	34.67586	1.456833	14.65792	30.45720	2.649242	8.845209	1.878	100.00%	
	0	0	0	0	0	0	0	0	0		
9	0.014967	0	0.000003	1.307869	0.030377	0	0.155576	0	1.151218		8,9,11,15,20,
	4.518	8.432	151.4646	0.71251	4.043866	4.920256	0.539724	3.971686	0.689	100.00%	
	0	0	0	0	0	0	0	0	0		
10	0.003389	0.089959	0	0	0.043792	0	0	0.050044	0.577647		8,9,10,20,
	24.42	10.196	114.6907	0.51843	7.873525	12.64898	2.940263	6.570573	0.565	100.00%	
	0	0	0	0	0	0	0	0	0		

Table B2 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY	
	0.010635	0	0.000005	0.691663	0	0.000239	0.277220	0.003919	0.544705		1,3,8,9,11,15,
11	44.812	11.104	122.2688	0.755825	20.84858	15.63885	2.319847	9.774013	0.578	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.011150	0	0.000012	0.416928	0	0	0	0.122834	0.187017		1,8,12,15,
12	50.726	14.84	51.79790	1.040302	14.55506	26.12024	2.910996	5.986654	1.415	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.042606	0.157659	0.000037	0	0	0	2.010344	0	0.642342		3,8,9,15,
13	6.75	4.358	168.3161	0.320335	5.752541	8.477987	0.370898	4.29258	0.396	98.10%	
	0	0	0	0.040481	3.203563	5.095876	0	1.917735	0		
	0.005954	0.037413	0.000002	0	0.017972	0.015425	0	0.011005	0.218266		1,3,8,9,15,20,
14	39.674	13.773	114.5777	0.92262	15.64938	21.57968	3.619463	8.405238	1.344	75.17%	
	0	0	0	0.037226	0	0	0.562654	0	0		
	0	0.069616	0.000012	0	0.028885	0	0	0.119911	0		1,8,15,
15	5.757	3.056	62500	0.21119	4.3617	4.9469	1.4779	7.2888	0.182	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.012040	0	0.000002	1.052134	0.024437	0	0.125155	0	0.926114		8,9,11,15,20,
16	20.718	8.284	266.4464	0.60411	9.351525	17.06636	1.709477	8.610378	0.602	88.58%	
	0	0.273992	0	0	0	5.709805	0	3.072351	0		
	0	0	0.000012	4.437684	0	0	0.616527	0	4.360004		1,15,19,
17	2.219	1.554	1002.004	0.127855	4.44082	5.012698	0.433913	2.681035	0.168	57.97%	
	0.747611	0.278760	0	0	0.426845	1.469768	0	0.863617	0		
	0.013098	0	0.000001	1.200805	0.063303	0	0	0	0.956558		8,9,15,20,
18	13.774	7.292	314.2381	0.59085	5.793662	15.15580	2.743312	9.32922	0.662	89.05%	
	0	0.488775	0	0	0	6.207944	1.513774	4.681289	0		
	0.004540	0.053752	0.000000	0	0.009849	0	0	0	1.029547		11,15,19,20
19	26.721	16.345	116.8674	1.086198	23.13094	23.91687	2.516734	13.11878	0.75	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.006664	0.002189	0.000001	0.566808	0.013546	0	0.072498	0	0.520690		1,8,9,11,15,20,
20	37.566	18.102	171.2240	1.25216	17.23586	18.47946	3.778614	9.082145	0.946	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.006539	0.041865	0	0	0.017716	0.013324	0.037872	0	0.326424		1,3,8,9,20,
21	25.807	14.983	86.83495	1.063731	11.84973	16.96845	1.971155	8.853482	1.499	79.60%	
	0	0	84.93534	0.094914	0	0	0	0.121231	0		

Table B3

DEA Results for MACOM #1 FY83

UNIT EVALUATED	u1 O1 SO1	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY	REFERENCE SET
	0	0.038980	0	0	0	0.003926	0	0.079433	0.028255		2,12,20,
1	42.024	23.445	18.27986	1.538125	30.72541	32.73009	5.063551	10.21331	2.131	91.39%	
	16.16612	0	154.2942	0.142680	5.673553	0	1.480134	0	0		
	0.002462	0.010941	0	0.565096	0	0	0.162625	0.089753	0		2,9,12,20,
2	40.675	17.07	112.1453	1.261886	18.20349	27.16743	2.563309	6.497167	1.509	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.011068	0.014948	0.000084	0.272758	0.044703	0	0	0	0.313195		3,9,15,17,20,
3	49.954	11.971	56.62193	0.965575	11.55224	19.53848	1.024778	10.02651	1.544	100.00%	
	0	0	0	0	0	0	0	0	0		
	0	0	0	1.040185	0	0	0	0.106919	0.475948		9,20,
4	17.367	11.129	58.62351	0.82935	12.37327	12.89622	1.522955	5.791663	0.8	86.27%	
	2.780122	0.422055	109.6291	0	1.281485	1.118160	0.107285	0	0		
	0.009161	0.178086	0	0	0.070165	0	1.000404	0.075178	0		3,5,9,20,
5	4.883	5.364	61.19501	0.435455	3.956194	3.905701	0.500212	2.952925	0.545	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.007760	0.014771	0	0	0.020925	0	0	0	0.210978		11,12,20,
6	65.635	23.759	7.013999	1.629613	24.23639	33.61589	4.05902	12.89652	2.336	86.03%	
	0	0	146.5504	0.034465	0	3.755669	0.427151	1.167150	0		
	0.021891	0.051898	0	0	0.059691	0	0	0	0.770235		7,11,20,
7	20.778	10.504	186.0811	0.684739	11.81068	13.70210	1.547052	5.860519	0.383	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.001789	0.044124	0	0	0.017545	0	0	0.062880	0.096729		8,9,12,20,
8	40.052	21.039	35.71683	1.43234	16.55021	27.50491	3.486705	8.445323	1.846	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.013864	0.104888	0.000279	0	0.064882	0	0.464522	0.073648	0		3,9,12,17,20,
9	5.546	8.409	147.2754	0.71024	4.038596	5.443833	0.972358	3.887154	0.679	100.00%	
	0	0	0	0	0	0	0	0	0		
	0.022730	0.042541	0.000126	0	0.064237	0	0	0	0.589254		3,10,12,20,
10	24.22	10.322	81.85315	0.54138	6.990409	19.28489	2.129646	6.492006	0.935	100.00%	
	0	0	0	0	0	0	0	0	0		

Table B3 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY	
	0 015325	0 027616	0 000050	0	0 041143	0	0	0	0 403939		3,11,12,20,
11	44 812	11 104	131 7991	0 755825	18 63043	18 98907	2 504183	8 200765	0 378	100 00%	
	0	0	0	0	0	0	0	0	0		
	0 012166	0	0 000074	0 434672	0 034179	0 009812	0	0	0 288303		3,9,12,15,20,
12	44 413	14 87	55 13895	1 047985	12 59094	16 15644	2 007774	5 991353	1.426	100 00%	
	0	0	0	0	0	0	0	0	0		
	0	0 159801	0.000207	0	0 098809	0	0	0	1 436263		7,9,17,
13	6 505	4 922	146 4557	0 36016	5 033003	8 697814	1.096711	4.573994	0.35	81 69%	
	0 112240	0	0	0 006587	0	2 136065	0 233134	1 167406	0		
	0 013472	0 025178	0 000077	0	0 038093	0	0	0.000051	0 348607		3,10,12,17,20,
14	33 813	13 106	126 4062	0.88686	14 17885	23.29181	2.275241	8.125425	1.318	79.54%	
	0	0	0	0 015119	0	3.249381	0 207678	0	0		
	0 056464	0	0.000385	1 988448	0 150485	0.053426	0.024629	0	1.266140		3,9,12,15,17,20
15	5 757	2 978	409.5004	0 259965	3.5098	4.2315	0.6731	5 3958	0.181	100.00%	
	0	0	0	0	0	0	0	0	0		
	0 000760	0	0.000098	1.306918	0.020909	0	0.195813	0	0.989778		7,9,15,17,20,
16	15 103	8 432	261 9858	0 603015	9.214614	15.61640	1.211421	8.050986	0.576	82.53%	
	0	0 044747	0	0	0	4.586748	0	2.416383	0		
	0 033059	0 129881	0.000330	0	0.158811	0	0.141920	0.005038	0.773562		3,9,10,12,17,20
17	1 538	1 233	2386.634	0.10544	4.932028	5.223706	0.662022	2.567701	0.142	100 00%	
	0	0	0	C	0	0	0	0	0		
	0 026646	0 054463	0.000219	0 408883	0 117762	0	0	0	0.667050		3,9,10,12,17,
18	9 057	7.272	267.0940	0 58935	4.741871	15.78681	1.59101	8 907848	0.662	93 70%	
	0	0	0	0	0	8.881913	0.580013	4.886689	0		
	0	0 050771	0	0	0	0.001100	0.441158	0	0.086908		3,5,20,
19	26 607	17 618	90.03455	1 176317	25.98239	19.18278	1.913548	13.40839	1.55	89 45%	
	9.164894	0	118.7233	0 127488	8 103911	0	0	2.804255	0		
	0 010007	0 022060	0 000081	0 152064	0.043370	0	0	0	0.273692		9,10,12,17,20,
20	37 087	18.671	259 6728	1 287765	16 56978	17.08814	1.903621	7.95215	1.028	100 00%	
	0	0	0	0	0	0	0	0	0		
	0 001780	0 061882	0	0	0 024907	0	0.366699	0	0.107635		3,5,9,20,
21	25 802	15.12	64.26239	1.070744	11.98782	20.11339	1.47836	9.22367	1.48	98.16%	
	0	0	106.3435	0 127843	0	5.720102	0	0.385041	0		

Table B4

DEA Results for MACOM #2 FY85

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY
1	0 0001 8 904 0	0 0 0	2 244300 10 236 0	0 0001 65 80494 0	111 0209 0 693742 0	0 0001 16.098 0	0.0001 31 354 0	10 97162 2 224 0	6 941647 4 459 0	74 90195 0.596 0	100.00
REF SET LAMBDA			12 0		8 0		1 1				
2	0 0001 46 049 29.85406	0 0 0	0.0001 20.67 1.562497	0 0001 66 85792 663 9454	65.45848 1.525868 0	0 463018 21.821 0	0.0001 36 582 7.797044	0.0001 5.947 0.938913	6.716435 10 529 0	13 44661 1 426 0	99 89
REF SET LAMBDA			21 1 578934		5 0.359130		1 0.117591				
3	0 0001 42 212 15 06786	0 0 0	0.0001 17 289 1.868189	0 0001 56 88699 505.9554	69 47338 1.310005 0	2.304657 18.052 0	0.559443 23.834 0	0.0001 4.669 0.296182	1.535614 10.336 0	18.53330 1.575 0	91.02
REF SET LAMBDA			21 1.084050		14 0.002909		12 0.199638		5 0.726618		
4	0 0001 2 265 0	0 0 0	62.99794 1.483 0	0.007500 876 4241 0	0.0001 0.099975 0	0.0001 2.252 0	14.36002 2.153 0	0.0001 0.414 0	36.27762 1.551 0	512.6400 0.025 0	100.00
REF SET LAMBDA			21 0		12 0		8 0		4 1		
5	0 0001 1 698 0	0 0 0	20.51943 4 873 0	0.0001 85.91286 0	0.0001 0 316338 0	4.153671 0.718 0	8.105595 2.811 0	0.0001 0.461 0	4 288356 1.209 0	75 71070 0.912 0	100.00
REF SET LAMBDA			21 0		18 0		5 1				
6	0 452566 46 233 0	0 0 0	7 586483 10 417 0	0 000254 188 3664 0	0.0001 0.716229 0	1.295164 15.35 0	0.0001 32.448 0	0 0001 4 511 0	3 789176 9.331 0	148.2077 0 302 0	100.00
REF SET LAMBDA			15 0		6 1		4 0				
7	0 562476 15 765 0	0 0 0	9.054771 7.763 0	0 0001 83 39588 350.8078	0.0001 0.495335 0.021472	0.0001 10.139 1 252390	2.636261 13 055 0	27 64645 1.637 0	0 0001 7.633 0.247169	45 26634 0.449 0	79 17
REF SET LAMBDA			18 0 470879		12 0 4[illegible]7377		11 0 091800		5 0 174516		

Table B4 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY
8	0 199488	0	10 26290	0 0001	0 0001	0 992002	0 0001	10 36751	6 455184	81 72324	
	23 874	0	9 278	181 2579	0 615065	12 356	16 03	2 694	4 632	0 366	100 00
	0	0	0	0	0	0	0	0	0	0	
REF SET			21		12		9		8		
LAMBDA			0		0		0		1		
9	0 0001	0	10 43363	0 0001	238 3436	11 02324	2 530375	9 362139	9.429581	104 7205	
	2 784	0	3 758	1123 595	0 254581	3 074	6 989	0 368	3.027	0.157	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			21		18		14		12		9
LAMBDA			0		0		0		0		1
10	0 0001	0	0 0001	0 0001	208 6132	10.81407	0.972921	0.0001	0.0001	83 94544	
	12 656	0	5 089	262 5360	0.378755	5 233	13.383	3 616	7.427	0 362	79 04
	35 38782	0	0 693880	1268 524	0	0	0	1 465494	0.796727	0	
REF SET			12		11		9				
LAMBDA			0 241748		1 631352		0 127041				
11	0 0001	0	0 0001	0.0001	1113.496	57.93260	4.953670	0 0001	0 0001	451.4758	
	25 503	0	1.5	832.5701	0 08973	0.518	3.648	0.477	1.43	0.115	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			12		11		9				
LAMBDA			0		1		0				
12	0 048754	0	0 0001	0.004088	118.7551	3.392649	2 076382	0.0001	1 739689	30 29091	
	25 174	0	11 824	124.5174	0.827437	12.027	15.539	2.368	9.787	0.327	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			21		12		9				
LAMBDA			0		1		0				
13	0 0001	0	1 390763	0 0001	54.19097	0.0001	0 984157	8.038635	2.183262	17.13109	
	40 012	0	19 437	35.03286	1.346354	19 21	25.74	3	12.231	1 392	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			21		18		13		12		9
LAMBDA			0		0		1		0		0
14	0 0001	0	5 802166	0.0001	131.0919	6.110793	1 407833	5.055298	5.192296	57.89376	
	15 499	0	6 737	105.1533	0 46455	6.297	11.13	1 589	4 418	0 357	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			21		18		14		9		
LAMBDA			0		0		1		0		

Table B4 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENCY
15	0 0001	0	13 18668	0 0001	0.0001	7 752356	0 0001	0.0001	3 906483	89 24733	
	15 822	0	7 583	37 17748	0 473115	7.239	23 888	2 506	6 503	0 207	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			15		11						
LAMBDA			1		0						
16	0 377237	0	13 79026	0.003011	0.0001	3.025150	0.0001	0 0001	8 337181	168.0317	
	19 015	0	5.876	757.0022	0.36737	7.358	15 276	2.752	4.447	0 242	90.48
	0	0	0	0	0 027777	0	3.999058	0 937770	0	0	
REF SET			14		12		11		8		4
LAMBDA			0.284542		0.047887		0.253857		0.239592		0.53208959
17	0 416575	0	0.0001	0 014148	531.9166	23.96750	0.0001	0.0001	0.0001	501.8879	
	3.807	0	1.918	436.6812	0.132355	2.162	6.529	1.194	2.373	0.096	78.17
	0	0	0 026408	0	0	0	1.781352	0.654606	0.254391	0	
REF SET			12		11		9		4		
LAMBDA			0.051841		0.061180		0.321992		0.019966		
18	0.0001	0	16 55686	0.0001	247 6912	20 26442	3.089941	0.134533	6.415408	140.3406	
	3 024	0	3.316	222.4252	0.18198	1.472	3.564	0.224	1 407	0.357	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			18		14		12		11		
LAMBDA			1		0		0		0		
19	0.0001	0	4 949452	0.0001	43.58322	5 231904	1.336923	0.0001	0.0001	33.33301	
	19 702	0	8 062	616.5228	0.519221	9.294	16.735	3.588	11.92	0.87	62.60
	5 529080	0	0	35.38014	0	0	0	0.900731	1.963690	0	
REF SET			18		12		11		5		
LAMBDA			0.668367		0.370834		0.535039		0.135108		
20	0.0001	0	3.280001	0.0001	43 49523	2.941309	0.0001	0.0001	3.925083	25.10284	
	35.387	0	14.119	189 1074	0.95207	13.266	25	5.512	8.366	1.121	87.74
	0 531010	0	0	199.3957	0	0	3.539713	1.941923	0	0	
REF SET			21		18		14		5		
LAMBDA			0.456179		0.299512		0.830970		0.401726		
21	0.0001	0	4.283680	0.0001	56.53683	3 830255	0.0001	0.0001	5.117438	32.70882	
	47 023	0	12 21	438 4042	0 842773	12.453	15.248	2.9	6.059	0.651	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			21		18		14		5		
LAMBDA			1		0		0		0		

Table B5

DEA Results for MACOMs #1 and #2

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENC
1	0.105589	0	4.015526	0.000374	0.0001	1.326803	0.486351	0.0001	3.414276	14.64367	
	50.79	0	23.565	29.51768	1.575665	29.63011	19.11532	5.819449	7.935924	1.659	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			1								
LAMBDA			1								
2	0.064398	0	0.0001	0.0001	74.61937	1.556605	0.0001	0.0001	5.858003	17.02091	
	41.295	0	17.408	252.0161	1.282491	17.84937	36.65980	4.617007	7.794262	1.56	98.38
	0	0	1.563039	50.18612	0	0	18.17077	0.544632	0	0	
REF SET			42		26		20		1		
LAMBDA			0.387958		0.677951		0.269518		0.259914		
3	0.416627	0	0.0001	0.0001	71.19850	0.0001	2.882146	11.15920	0.0001	10.95724	
	80.687	0	11.254	57.58146	0.91384	12.20430	19.50505	2.450487	10.11598	1.5	98.69
	0	0	1.978023	2592.422	0	5.491503	0	0	0.295886	0	
REF SET			32		26		9		4		
LAMBDA			2.890295		0.781996		0.308854		0.265233		
4	0.737840	0	0.0001	0.0001	125.6557	0.0001	5.086932	19.69591	0.0001	19.33358	
	15.132	0	9.346	488.8780	0.706575	10.41356	15.18643	0.322458	6.229739	0.848	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			4								
LAMBDA			1								
5	0.0001	0	0.0001	0.000534	144.4227	5.835200	0.0001	0.0001	4.700293	42.75963	
	11.526	0	8.3	294.8113	0.657605	7.96222	13.61274	2.518795	5.367827	0.662	95.13
	5.065528	0	1.215179	0	0	0	0.238690	0.334784	0	0	
REF SET			21		20		15		10		
LAMBDA			0.254959		0.262236		0.002916		0.253098		
6	0.110312	0	0.0001	0.0001	50.21191	0.457431	0.0001	4.071794	3.875980	10.07505	
	64.404	0	23.449	9.333843	1.617933	22.45047	32.50205	5.276858	11.48981	2.353	88.35
	0	0	0.267372	533.3502	0	0	2.847196	0	0	0	
REF SET			42		26		21		12		1
LAMBDA			1.010467		0.915671		0.183954		0.073058		0.128729
7	0.064283	0	6.725351	0.0001	0.0001	2.914053	0.0001	3.197002	3.209358	36.40442	
	25.594	0	12.144	85.10421	0.757919	11.68280	25.82272	3.37952	8.959907	0.725	83.33
	0	0	0	478.3129	0.042897	0	3.514270	0	0	0	
REF SET			39		32		30		20		10
LAMBDA			0.348829		0.297447		0.030636		0.396644		0.901076

Table B5 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENC
8	0.077421	0	0.0001	0.0001	56.53379	1.752210	0.0001	0.0001	3.375857	13.90844	
	44.363	0	23.357	23.90834	1.594364	18.18247	39.80743	4.909878	10.82273	2.272	93.57
	0	0	0.105489	436.0679	0	0	13.98452	0.274830	0	0	
REF SET			42		26		21		20		
LAMBDA			0.457535		1.331971		0.085889		0.565114		
9	0.089552	0	0.0001	0.0001	139.8841	5.754180	0.628078	0.0001	3.749796	37.26012	
	5.292	0	8.441	151.4646	0.711375	5.710307	8.190885	1.942642	9.657363	0.692	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			9								
LAMBDA			1								
10	0.134464	0	16.11114	0.0001	165.2382	15.53168	0.0001	0.0001	15.14275	111.3574	
	4.511	0	3.722	118.0038	0.23854	2.544618	8.825912	1.158742	3.192209	0.109	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			10								
LAMBDA			1								
11	0.372333	0	7.460589	0.0001	0.0001	0.0001	1.196710	16.16938	2.796812	40.79907	
	45.64	0	10.245	162.3534	0.688226	21.44733	17.02951	2.255635	7.782973	0.524	93.44
	0	0	0	1403.351	0.007398	10.95808	0	0	0	0	
REF SET			42		33		32		30		4
LAMBDA			0.319282		0.227986		0.903408		0.566443		0.017872
12	0.248098	0	0.0001	0.000490	83.55767	1.182456	0.615391	8.114614	3.844109	17.46619	
	51.64	0	14.766	55.56296	1.043105	13.50181	20.31280	2.326554	7.268419	1.415	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			12								
LAMBDA			1								
13	0.0001	0	0.0001	0.000801	216.5823	8.750568	0.0001	0.0001	7.048909	64.12359	
	6.826	0	4.366	211.6446	0.320895	5.391996	9.773071	1.503468	3.890375	0.396	69.67
	1.057828	0	0.324703	0	0	0	0.052147	0.041304	0	0	
REF SET			21		20		15		10		
LAMBDA			0.091569		0.129564		0.002277		0.262272		
14	0.172296	0	3.962945	0.0001	65.82730	1.400793	0.0001	9.007530	8.325933	27.64439	
	32.294	0	11.26	201.1950	0.756418	9.988661	15.56383	2.164391	5.136244	0.859	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			14								
LAMBDA			1								

Table B5 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENC
15	0 215284	0	3 813660	0 001027	78 12231	1 266813	0 0001	11 13992	9 234094	29 10252	
	7 943	0	3 73	62500	0 253815	3 0026	6 6038	1 2107	7 7813	0 373	100 00
	0	0	0	0	0	0	0	0	0	0	
REF SET			15								
LAMBDA			1								
16	0 093017	0	0 0001	0 0001	120 4840	4 637540	0 575695	0 0001	2 168508	49 24581	
	14 305	0	7 798	231 4707	0 578615	9 273363	16 27916	3 156487	9 357042	0 555	71 07
	0	0	0 278585	15 13163	0	0	0	0 287569	0	0	
REF SET			33		32		20		10		9
LAMBDA			0 133677		0 119945		0 132255		0 519098		0.240002
17	0 0001	0	0 0001	0 002247	333 0967	0.0001	0 0001	25 23373	15.39281	200.2889	
	2 099	0	1 551	2531 645	0.12763	4 329493	4 826782	0 822503	2 962144	0.168	48 20
	1 451906	0	0 291497	0	0	0 320784	0 022947	0	0	0	
REF SET			33		30		20		15		
LAMBDA			0 063130		0 017428		0 049457		0 039872		
18	0 060534	0	0 0001	0 0001	135.8065	7 475854	0.0001	5.992716	0.0001	61.57924	
	12 813	0	7 272	201 8163	0 58935	6 40662	17.01283	1.891752	11.47715	0 662	80.83
	0	0	0.237391	711 5432	0	0	4 048107	0	1 429089	0	
REF SET			32		30		10		9		
LAMBDA			0 319999		0 492343		0 015770		0.606618		
19	0 081840	0	0 0001	0 0001	83 15681	3 826298	0 601644	0.0001	0.0001	47 43679	
	28 837	0	6 261	85 79787	0 540095	12 42371	25.14478	5.071001	16.45796	0.787	47 28
	0	0	1 330419	648 5244	0	0	0	0.549609	0.715482	0	
REF SET			33		32		10		9		
LAMBDA			0 275699		0.750772		0.339833		0.229892		
20	0 060515	0	0 0001	0 0001	79.68608	3 064230	0 381340	0.0001	1.434215	32 58783	
	32 279	0	17 83	245 6338	1.23008	16 85609	18 95926	3.888255	9.038273	0.864	100 00
	0	0	0	0	0	0	0	0	0	0	
REF SET			20								
LAMBDA			1								
21	0 042820	0	0 0001	0 0001	91 98183	3 682673	0.100068	1 623034	2 157354	28 67051	
	27 306	0	15 244	71 55891	1 074365	9 811973	21 51981	2 137524	7.474892	1 469	100 00
	0	0	0	0	0	0	0	0	0	0	
REF SET			21								
LAMBDA			1								

Table B5 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENC
22	0.0001	0	7.801246	0.0001	29.02947	0.109765	0.0001	16.38292	7.652260	46.43088	
	8.904	0	10.236	65.80494	0.693742	16.098	31.354	2.224	4.459	0.596	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			22								
LAMBDA			1								
23	0.053501	0	0.0001	0.0001	62.22533	1.297504	0.0001	0.0001	4.885694	14.19454	
	46.049	0	20.67	66.85792	1.525868	21.821	36.582	5.947	10.529	1.424	97.42
	0	0	1.648885	272.3600	0	0	12.98224	0.948068	0	0	
REF SET			42		24		20		1		
LAMBDA			0.265446		0.313645		0.778844		0.155423		
24	0.093701	0	0.0001	0.0001	63.75114	2.036203	0.032959	0.0001	3.640013	15.76713	
	42.212	0	17.289	56.88699	1.310005	18.052	23.834	4.669	10.336	1.575	87.48
	0	0	1.813603	370.0933	0	0	0	0.270724	0	0	
REF SET			42		32		26		21		20
LAMBDA			0.364200		0.091558		0.490508		0.131015		0.568195
25	0.0001	0	45.61021	0.003080	0.0001	0.0001	37.99139	17.16352	0.0001	443.9379	
	2.265	0	1.483	876.4241	0.099975	2.252	2.153	0.414	1.551	0.025	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			25								
LAMBDA			1								
26	0.026803	0	12.65009	0.000650	120.9298	13.00623	2.315340	0.0001	4.114275	86.81896	
	1.698	0	4.873	85.91286	0.316338	0.718	2.811	0.461	1.209	0.912	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			26								
LAMBDA			1								
27	0.459103	0	0.0001	0.0001	109.9569	0.861941	0.0001	0.0001	5.571020	115.1731	
	46.233	0	10.417	188.3664	0.716229	15.35	32.448	4.511	9.331	0.302	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			27								
LAMBDA			1								
28	0.565417	0	8.983587	0.0001	0.0001	0.0001	3.358488	23.28893	0.0001	40.15404	
	15.765	0	7.763	83.39588	0.495335	10.139	13.055	1.637	7.633	0.449	78.66
	0	0	0	126.0505	0.035886	0.649335	0	0	0.127921	0	
REF SET			39		33		32		4		
LAMBDA			0.318326		0.493541		0.041884		0.084557		

Table B5 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENC
29	0 271770	0	10 05899	0 001016	0 0001	0 0001	0 0001	13 69547	7 299443	80 02876	
	23 874	0	9 278	181 2579	0 615065	12 356	16 03	2 694	4 632	0 366	100 00
	0	0	0	0	0	0	0	0	0	0	
REF SET			29								
LAMBDA			1								
30	0 0001	0	0.0001	0.001211	387 4529	15.45645	0 441581	5.042884	9.614732	117.4591	
	2 784	0	3 758	1123 595	0.254581	3.074	6.989	0 368	3.027	0.157	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			30								
LAMBDA			1								
31	0 184452	0	0.0001	0.0001	183.7721	8.466537	1.327527	0.0001	0.0001	104.7712	
	12 656	0	5.089	262.5360	0 378755	5 233	13 383	3 616	7.427	0 362	71.97
	0	0	0.265041	81.31028	0	0	0	1.150099	0.271519	0	
REF SET			33		32		10		9		
LAMBDA			0 064713		0.270939		0.686547		0.192764		
32	0 878123	0	0.0001	0.0001	863.9453	39.83517	6.234589	0.0001	0.0001	492.3600	
	25.503	0	1 5	832.5701	0 08973	0.518	3.648	0.477	1.43	0.115	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			32								
LAMBDA			1								
33	0 240702	0	2 002823	0 0001	84 89675	2.492368	1.456779	11.26581	1.202125	27.35389	
	25 174	0	11 824	124 5174	0.827437	12.027	15.539	2.368	9.787	0.327	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			33								
LAMBDA			1								
34	0 276924	0	2.594800	0.0001	25.54106	0.115509	2.091330	8.769936	0.0001	12.67183	
	40 012	0	19.437	35.03286	1 346354	19.21	25.74	3	12.231	1 392	95.91
	0	0	0	818 0939	0	0	0	0	0.772992	0	
REF SET	PICKETT		33		32		20		4		1
LAMBDA	0 619908		0 071085		0.317217		0.508140		0.646928		0.040683
35	0 390246	0	13.94404	0.0001	0.0001	2 904193	0.0001	12.80220	7.533370	109.2842	
	15.499	0	6 737	105 1533	0 46455	6.297	11.13	1.589	4 418	0.257	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			35								
LAMBDA			1								

Table B5 (Cont'd)

UNIT EVALUATED	u1 O1 SO1	u2 O2 SO2	u3 O3 SO3	u4 O4 SO4	u5 O5 SO5	v1 I1 SI1	v2 I2 SI2	v3 I3 SI3	v4 I4 SI4	v5 I5 SI5	EFFICIENC
	0.477807	0	12.18994	0.0001	0.0001	2.749838	0.0001	0.0001	7.039784	165.7563	
36	15.822	0	7.583	37.17748	0.473115	7.239	23.888	2.506	6.503	0.207	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			36								
LAMBDA			1								
	0.470970	0	13.56045	0.001345	0.0001	2.811335	0.0001	0.0001	8.305589	175.1133	
37	19.015	0	5.876	757.0022	0.36737	7.358	15.276	2.752	4.447	0.242	89.65
	0	0	0	0	0.028374	0	4.177316	0.962956	0	0	
REF SET			33		32		29		15		10
LAMBDA			0.202853		0.239876		0.315660		0.007515		0.043235
	0.853316	0	0.0001	0.002516	496.8386	14.01969	0.0001	0.0001	15.78957	335.6247	
38	3.807	0	1.918	436.6812	0.132355	2.162	6.529	1.194	2.373	0.096	70.11
	0	0	0.105494	0	0	0	0.211998	0.250910	0	0	
REF SET			35		33		32		15		10
LAMBDA			0.074069		0.005128		0.031079		0.005729		0.375027
	0.363044	0	13.01293	0.0001	306.2370	17.84048	3.271799	19.78012	7.328416	132.5946	
39	3.024	0	3.316	222.4252	0.18198	1.472	3.564	0.224	1.407	0.357	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			39								
LAMBDA			1								
	0.013789	0	7.628958	0.000143	0.0001	4.670484	1.405611	0.0001	0.023839	37.68402	
40	19.702	0	8.062	614.5228	0.519221	9.294	16.735	3.588	11.92	0.87	61.87
	0	0	0	0	0.066478	0	0	0.532973	0	0	
REF SET	40		33		32		15		10		9
LAMBDA	0.362625		0.194888		0.429857		0.001233		0.127734		0.406392
	0.026975	0	3.499891	0.0001	36.46004	3.392324	0.0001	0.0001	3.311299	24.34614	
41	35.387	0	14.119	189.1074	0.95207	13.266	25	5.512	8.366	1.121	85.10
	0	0	0	492.8385	0	0	5.726128	1.791685	0	0	
REF SET			37		32		26		20		10
LAMBDA			0.155809		0.556123		0.323601		0.620464		0.034488
	0.144901	0	6.100336	0.0001	22.13805	3.127174	0.0001	0.0001	4.978104	28.84047	
42	47.023	0	12.21	438.4042	0.842773	12.453	15.248	2.9	6.059	0.651	100.00
	0	0	0	0	0	0	0	0	0	0	
REF SET			42								
LAMBDA			1								

USA-CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: CEIM-SL (2)
ATTN: CECC-P
ATTN: CECW
ATTN: CECW-O
ATTN: CECW-P
ATTN: CEEC
ATTN: CEEC-C
ATTN: CEEC-E
ATTN: CERD
ATTN: CERD-C
ATTN: CERD-M
ATTN: CERM
ATTN: DAEN-ZCI

USAEHSC, ATTN: Library 22060
ATTN: DET III 79906
ATTN: CEHSC-F 22060
ATTN: CEHSC-TF 22060
ATTN: CEHSC-E 22060

US Army Europe
AEAEN-ODCS/Engr (2) 09403
AEUES 09081
V Corps
ATTN: DEH (12)
VII Corps
ATTN: DEH (16)
21st Support Command
ATTN: DEH (12)

AMC - Dir., Inst., & Servc
ATTN: DEH (23)

FORSCOM
FORSCOM Engr, ATTN: Spt. Det.
ATTN: DEH (28)

HSC
Ft. Sam Houston AMC 78234
ATTN: HSLO-F
Fitzsimons AMC 80045
ATTN: HSHG-DEH
Walter Reed AMC 20307
ATTN: Facilities Engineer

INSCOM - Ch, Instl. Div
ATTN: Facilities Engineer (5)

MDW, ATTN: DEH (3)

MTMC
ATTN: MT-LOF 20315
ATTN: Facilities Engineer (3)

TRADOC
HQ, TRADOC, ATTN: ATEN-DEH
ATTN: DEH (18)

CECRL, ATTN: Library 03755

CEWES, ATTN: Library 39180

Defense Technical Info. Center 22314
ATTN: DDA (2)

US Govt Print Office 22304
Receiving Sect/Depository Copies (2)

155
12/88